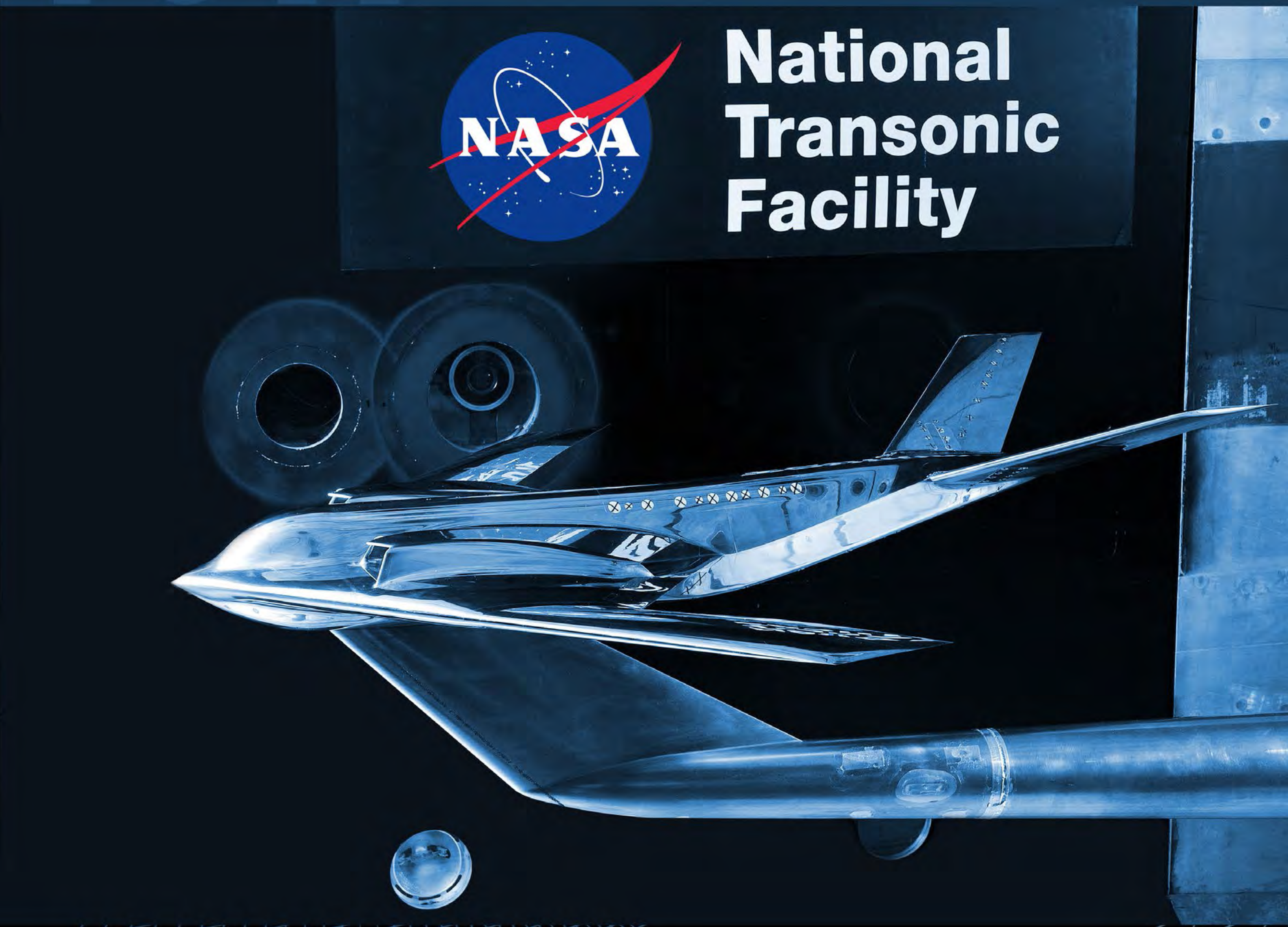
National Aeronautics and Space Administration

NTF USER GUIDE



www.nasa.gov

SP-2011-5-110-LaRC

TABLE OF CONTENTS

CUSTOMER WELCOME

Dear Customer,

Welcome to the National Transonic Facility (NTF) at NASA Langley Research Center! We are very pleased that you have considered the NTF for your testing needs. Our primary objectives are to make your experience both pleasant and successful. Our knowledgeable staff is here to fully support you during your time with us.

As one of the most flexible tunnels for evaluating and assessing aeronautical and aerospace vehicle performance over a wide range of subsonic and transonic conditions – testing in either air or cryogenic nitrogen – we are confident that our unique capabilities will fulfill your test requirements comprehensively and bring them to a productive conclusion.

Your initial interface will be with the NTF Facility Manager. He will review your test requirements and provide guidance with respect to the facilities capabilities and its availability to meet your testing schedule. An NTF test engineer will also be assigned to assist you. Please feel free to contact them for specific technical requests and any additional information beyond that contained in this booklet. You will also be assigned a preparation area for your model, and provided with an office and landline access.

To orient and guide you during your time with us, and in order to provide a secure and safe operating environment for multiple clients, we offer guidance and instructions in Chapter VIII – the “Facility Operations” section – of this User Guide. Please familiarize yourself with the procedures described therein.

We are at your service and very much look forward to working with you.

Sincerely,
The NTF Staff

II

HISTORY and INTRODUCTION

II - HISTORY and INTRODUCTION

For more than a half-century, flight's transonic regime preoccupied aerodynamicists. By the early 1960s, decision makers and the aeronautics research community had both endorsed the pressing national need for a large transonic tunnel capable of achieving full-scale flow similarity (full scale Reynolds numbers) across a broad range of Mach numbers. Although extensive studies of various alternatives began in 1966, the projected price tag proved excessive.

It was only in the early 1970s, when NASA Langley Research Center engineers demonstrated the cost-effectiveness of a pressurized cryogenic option, that construction of such a facility was finally deemed feasible.

To leverage the success of its unconventional 0.3 meter transonic cryogenic wind tunnel design – operational in 1973 – NASA proposed construction of a 2.5 meter (8.2 foot) pressurized cryogenic transonic tunnel that would fulfill all U.S. commercial, military and scientific research requirements. In 1974, the United States Congress authorized construction of the National Transonic Facility (NTF) at NASA Langley in Hampton, Virginia.

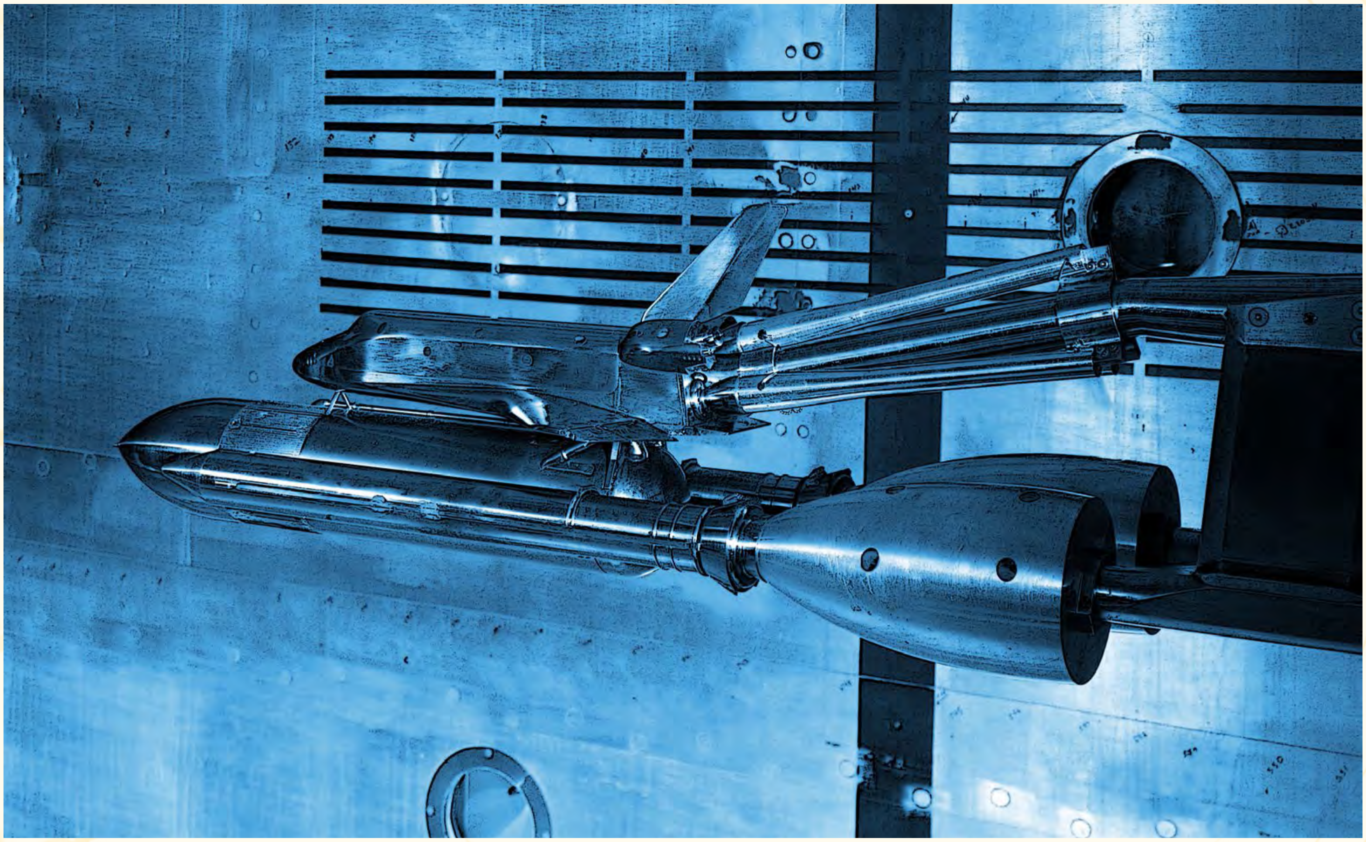
To make room for the new facility, Langley razed its 4-Foot Supersonic Pressure Tunnel. While the tunnel itself was removed, its drive motors, buildings and cooling towers were spared, becoming an integral part of the new complex.

Groundbreaking on the 497-foot-long, 230,000-cubic-foot, aluminum-and-stainless-steel NTF began in 1979. The facility was officially dedicated in 1983 by then-Vice President George H.W. Bush in a ribbon-cutting ceremony on the Langley grounds. Full operation commenced in 1984.

Facility Overview

The NTF is the world's largest fan-driven, closed-circuit, continuous-flow, pressurized cryogenic transonic wind tunnel, and features a wide range of customizable instrument and measurement techniques. Independent control of total temperature, pressure, and fan speed allow isolation and study of pure compressibility (Mach) effects, viscous (Reynolds number) effects, and aeroelastic (dynamic pressure) effects.

The facility provides the highest transonic Reynolds number testing capability in the world in both operational modes. When operating in warm air up to 150°F (65°C) as a conventional pressure tunnel, it can achieve Reynolds numbers up to 20 million per foot (65 million per meter). Typically the NTF operates at 120°F (49°C) in warm air. Operating in high-pressure air allows wind tunnel models to be constructed from conventional materials. . To realize the full Reynolds number capability of 145 million per foot (475 million per meter), liquid nitrogen at -320°F (-195°C) is vaporized into nitrogen gas to pressurize and cool the tunnel to operating temperatures as low as -250ºF (-157ºC). In cryogenic mode, the NTF provides full-scale-flight Reynolds numbers without an increase in model size; nevertheless, cryogenic-capable material selection must be considered.

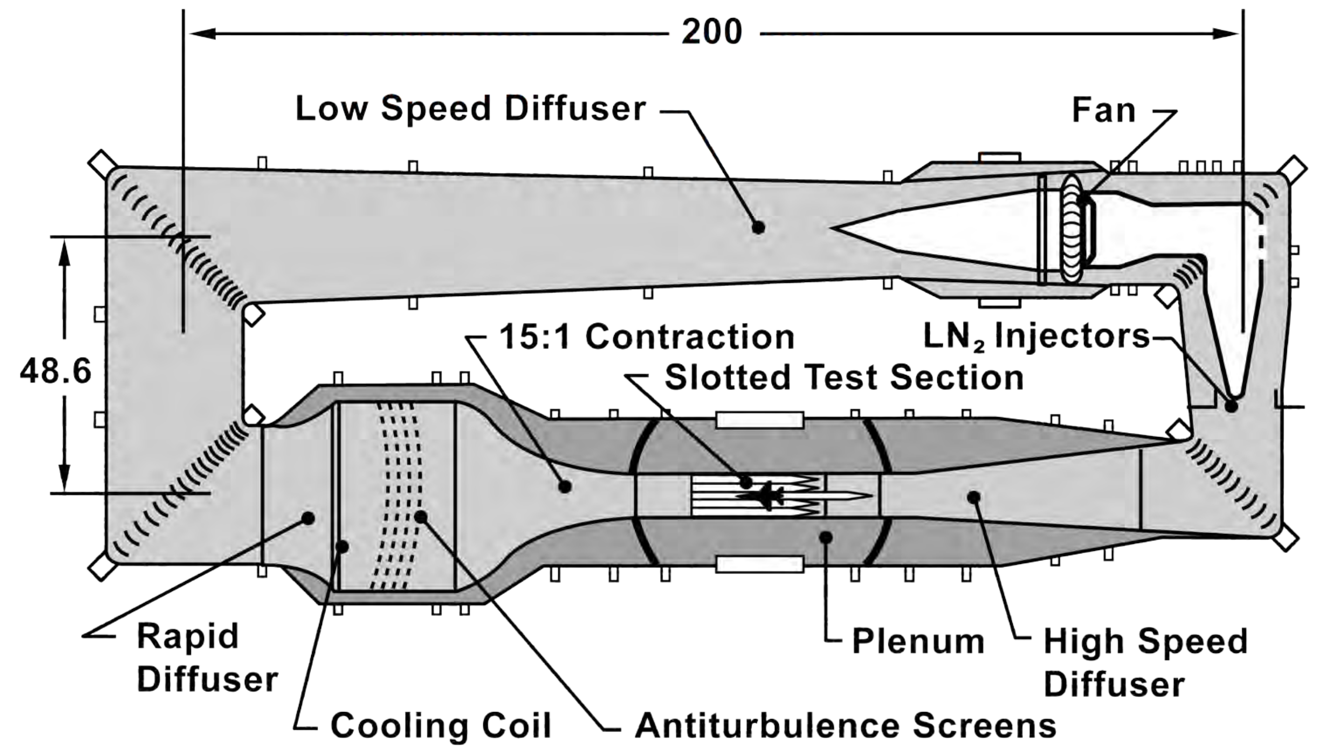


Test Section Details

The NTF test section is 8.2 feet (2.5 meters) by 8.2 feet (2.5 meters) square and 25 feet (7.6 meters) long, with a cross-sectional area of 67.2 square feet (6.2 square meters).

The test section has 12 slots and 14 re-entry flaps in the ceiling and floor, representing an openness ratio of 6%. The 6% openness ratio is based on the wall-surface area and the wall divergence angle, which is set at zero. These features serve as a passive plenum evacuation system to de-block the test section at near-sonic test conditions.

Upstream of the test section, four fine-mesh screens in the settling chamber and more than 3,500 square feet of sound-absorbing panels placed at strategic locations ensure high-quality, low-turbulence flow in the test section.



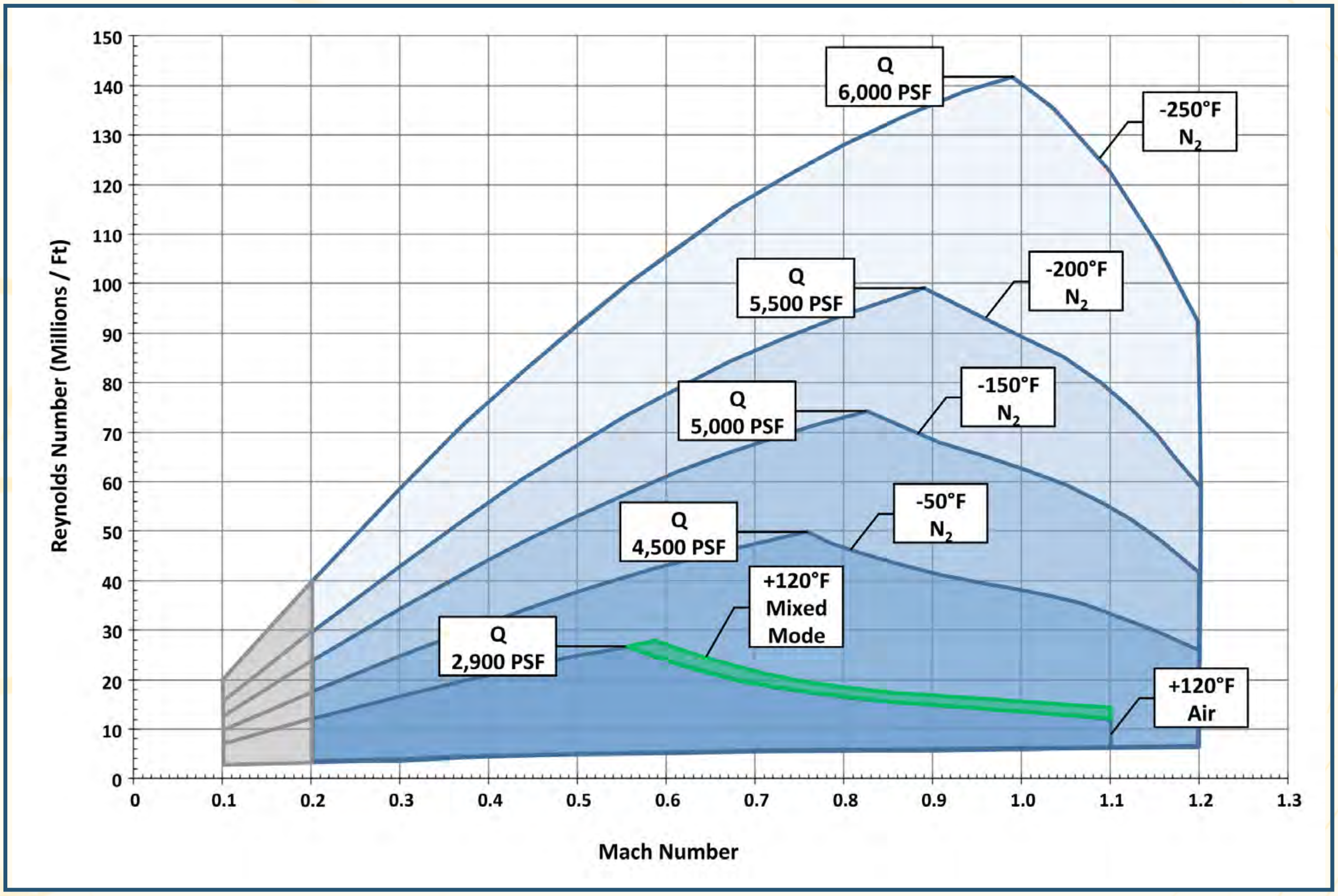
HISTORY and INTRODUCTION

Pressures and Temperatures

The facility can operate from 14.7 psia (101KPa) to 133 psia (910 KPa), or 1 to 9 atmospheres (1.01 to 9.1 bar) in either test gas. Pressures are fine-tuned to within ±0.07 psi (±482 Pa). Two large vent valves connected to the tunnel circuit between turns three and four control pressure.

For air-mode operations, pressure in the tunnel is increased with dry, high-pressure air from a NASA Langley center-wide air-distribution system. During air operations, temperature is controlled by a water-fed heat exchanger (cooling coils) located in the settling chamber. For cryogenic operations, these cooling coils are drained and dried. During nitrogen operations, the pressure and temperature is controlled by evaporating liquid nitrogen (LN2) that is dispersed into the tunnel circuit just upstream of the fan through 296 nozzles in 12 bundles at a maximum rate of 1,100 lbs/sec (9,680 gal/min; 36,000 liters/min). These two test modes provide the ability to operate the tunnel between +150°F and -250°F (+65°C and -157°C).

To ensure minimal energy consumption due to heat loss, the interior of the pressure shell is thermally insulated. Temperature can be maintained within ±0.3°F (±0.17°C) for N2 operations, or ±1°F (±0.56°C) for air operations.



HISTORY and INTRODUCTION

Fan Drive and Liquid Nitrogen Plant

The tunnel drive system is powered by a variable-speed motor that has variable maximum torque or power output up to 360 revolutions per minute (RPM). At 360 RPM the maximum power is 135,000 HP (101 MW), and that maximum power level is maintained up to 600 RPM. The compressor consists of a fixed-pitch, single-stage, 25-bladed fan with variable-pitch, inlet-guide vanes. To maintain rapid-response, fine Mach-number control, the inlet guide vanes are varied to achieve the required compression ratio. Mach numbers are maintained to ±0.001 or better.

NASA Langley constructed a liquid nitrogen (LN2) plant immediately adjacent to the NTF that became operational in 2008, thereby eliminating the need to truck or pipe in LN2 from offsite locations. The plant has a production capacity of 430 tons of LN2 per day and stored in two tanks with a total capacity of 3,800 tons (1,150M gallons; 4.4M liters). With the increased LN2 production capacity, the NTF can now fill the LN2 tanks in eight days. Before installation of the new plant 13 days were required to fill the tanks from a nearby, off-site plant. Having an on-site LN2 plant reduced overall test time and lowered operational costs.

Notable Studies

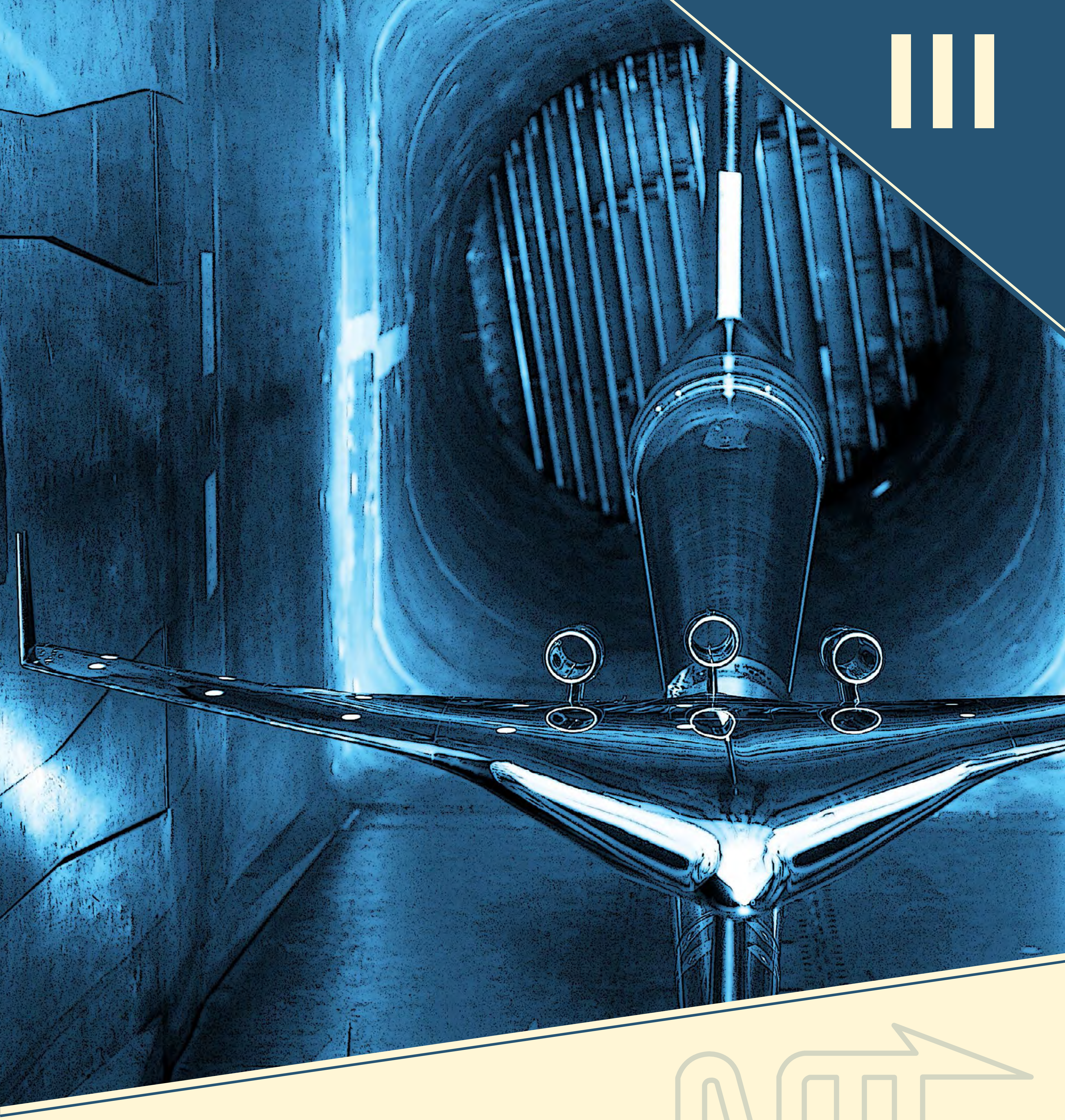
As the world's largest pressurized cryogenic wind tunnel, the NTF possesses unique capabilities to duplicate actual flight conditions. The facility supports advanced aerodynamic concept development and assessment, advanced computational fluid dynamics tool validation, and risk reduction for vehicle development.

NTF studies support research in stability and control, cruise performance, stall-buffet onset, propulsion/airframe integration, and configuration aerodynamics validation for both full-span and half-span models.

Notable vehicles tested in the facility have included the Boeing 767, 777 and 787; the space shuttle and the shuttle booster; the Delta II heavy launch vehicle; the A-6 Intruder; the F-18 Hornet; the Grumman X-29; even a Seawolf submarine.

Most recently, models related to the joint NASA-Boeing project to develop an Advanced Hybrid Wing Body, or AHWB, and the Orion Multi-Purpose Crew Vehicle (America's new spacecraft for human space exploration) have also undergone evaluation in the NTF.

More details of notable studies are presented in Chapter VI.



III

TEST SUPPORT

III - TEST SUPPORT

The National Transonic Facility provides a secure testing environment and state-of-the-art analytical tools. NASA Langley continually invests to maintain, upgrade and modernize testing capabilities and methods to meet stringent Center-specific, industry, and overall NASA goals.

NTF personnel work collaboratively with Langley's research and engineering directorates. The Center's internationally recognized subject matter experts provide a critical mass of excellence, with core competencies in aerosciences, structures, and materials: all specialists who identify and deliver solutions to complex aerospace systems problems.

As we strive to exceed customer and stakeholder expectations, we measure success by meeting the highest standards in technical operation and responsiveness to testing requirements. As we continue to support NASA's wide array of missions, we also fulfill the needs of those engaged in a variety of projects for other government agencies, industry, and academic interests.

Proactive Planning

Regardless of the facility in which it occurs, wind tunnel testing is a complex venture requiring proper advanced planning and coordination between facility and customer. For test customers who have previously worked with the NTF, this planning period may require only a few months to accomplish. A longer planning period may be required for first-time NTF tests that involve new models and/or new test techniques.

To ensure a smooth, efficient and productive NTF experience, the NTF facility manager and test engineering staff work proactively and closely with customers to provide the necessary guidance in test planning, model design, instrumentation selection and calibration, pre-test set up, and data reduction methodologies.

NTF personnel will also assist in sequencing the testing and model configuration order in a manner that minimizes test time and cost while maximizing data acquisition.

Defining Test Requirements

To properly plan for a wind tunnel test entry, NTF recommends that customers develop a preliminary set of test requirements and necessary hardware. These should include test plans, a model stress-analysis report compliant with NASA procedures, instrumented test articles, and any associated support hardware essential for successful test-program completion.

Typically, customers also provide personnel to monitor and/or assist with the test.

To ensure customer-supplied requirements are completely fulfilled, NTF personnel follow a simplified checklist to:

- Assist in project definition, technical approach, and overall goals and objectives
- Obtain the technical details of the vehicle configuration to be investigated
- Develop a time-and-cost estimate, and a mutually agreed-upon test-entry date
- Establish test-program roles and responsibilities
- Collaborate to develop testing capabilities necessary to accomplish the desired program

Pre-test activities are iterated with the customer. They include communication of facility and support system specifications, and definition of:

- Data types to be acquired
- The types of instrumentation to be utilized
- Model-design criteria
- The test matrix and schedule
- Data-reduction methodologies

To ensure that tests are successful, NTF staff members also coordinate with customers on a Systems Requirements Review and a preliminary Test Design Review.

The resultant estimates define the necessary user occupancy hours, electrical energy in megawatt hours, and liquid nitrogen expended in tons. Each of these three estimate elements is associated with a cost rate. A customer's final cost is based upon actual resource consumption during the test.

Model Sizing

The NTF follows industry standard guidelines with respect to model-sizing criteria, based upon ventilated test section walls with a 6% openness ratio. These criteria are recommendations to minimize blockage and wall interference effects for performance (drag validation) test programs at transonic speeds. They are as follows:

- Wing Span: 60% of test section width or less (approximately 59 inches, or 1.5 meters)
- Cross-Sectional Area: 0.5% of test section cross sectional area or less (approximately 0.34 square feet, or 0.031 square meters)

These guidelines may not be followed in every instance, either because of model design criteria or test article configuration. Nevertheless, in most cases, post-test wall interference corrections can be applied to the data to correct for any adverse effects.

Model Integrity

The NTF must comply with Langley Procedural Requirement (LPR) 1710.15: "Wind-Tunnel Model Systems Criteria." This document iterates criteria for the design, analysis, quality assurance, and documentation of wind-tunnel model systems to be tested in the NTF. The criteria are intended to prevent model system loss and/or potential facility damage.

LPR 1710.15 specifies that design loads data will be established by research personnel and will be consistent with the safe operating limits of the facility. In general terms, models and model support hardware should be designed to a safety factor of 4 on ultimate, or 3 on yield. The design-loads data is a part of the Model Systems Report that is required preferably four weeks prior to the test entry.

The documentation also includes, where applicable, aerodynamic and thermal loads for the extremes of the test condition model configurations, design cycle-life requirements, and inertia driving forces and frequencies for dynamic and transient testing.

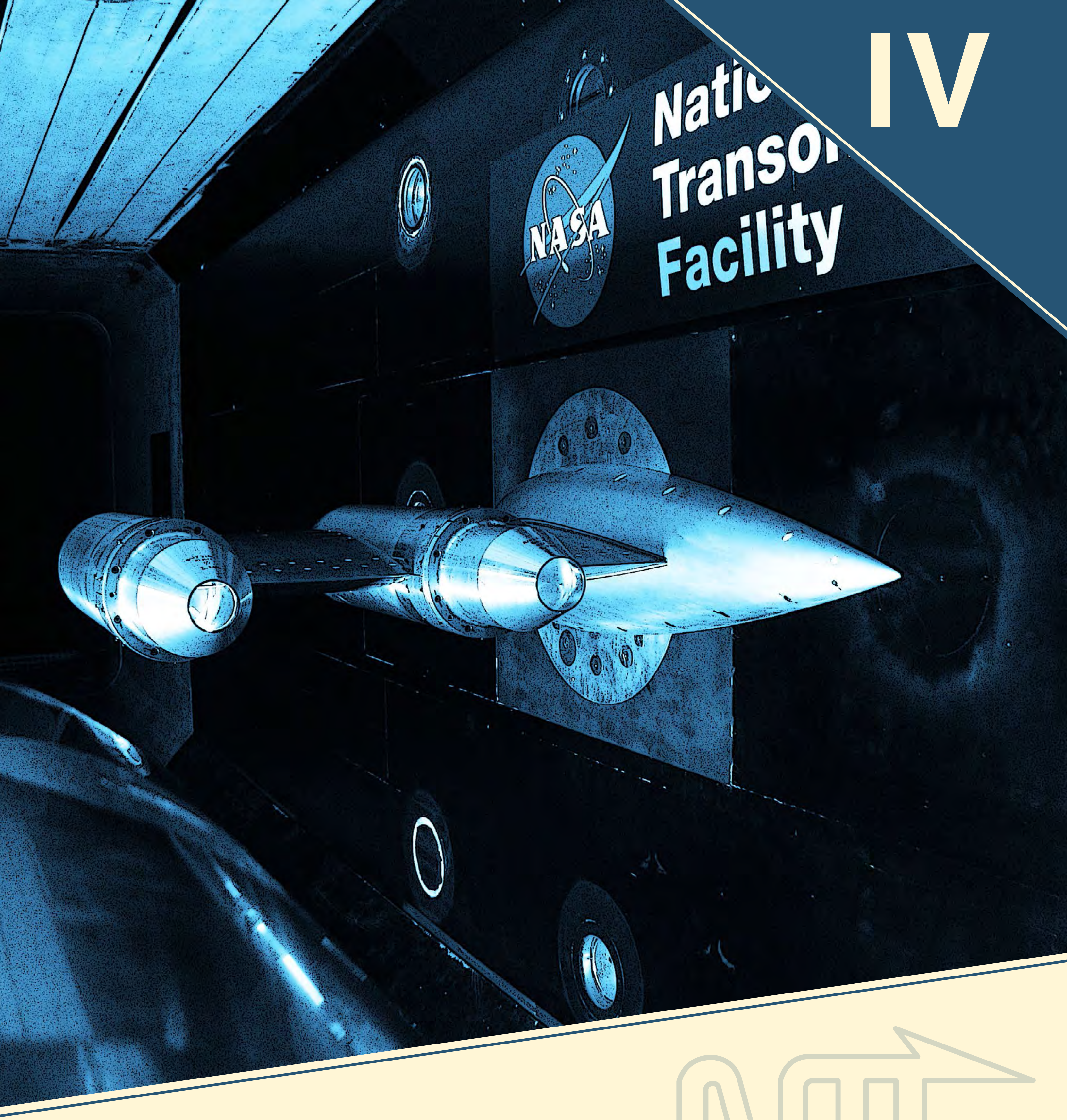
A list of all critically loaded/stressed components, including fasteners, is generated and included in the Model Systems Report.

Contract Assistance

For non-NASA test programs, NASA is required to create and execute a Space Act Agreement (SAA) for the reimbursable use of NASA facilities, personnel or equipment by a public or private entity wanting to advance research and development efforts.

The agreement involves a transfer of funds or other financial obligations from the private entity to NASA. The terms, conditions and schedules are negotiable, but NASA must be paid in advance for each stage of the effort. No goods or services are provided to NASA. Instead, NASA provides data, facilities and services to the paying entity.

NTF can assist in the development of an appropriate SAA. Additional information on SAAs can be found at http://www.nasa.gov/offices/ogc/about/index.html



IV

SYSTEMS and EQUIPMENT

IV - SYSTEMS and EQUIPMENT

The National Transonic Facility provides testing to support studies of stability and control, cruise performance, stall buffet onset, and configuration aerodynamics validation for both full-span and half-span models. The facility features and accommodates:

- Precision force and moment testing
- Static and dynamic pressure measurements
- Strain gauges
- Accelerometers
- Model deformation / wing twist Pressure Sensitive Paint (PSP)
- Temperature Sensitive Paint (TSP)
- Tracer PSP
- Focusing Schlieren
- Retro-reflective background-oriented Schlieren
- Mini-tufts

The Facility's model support system includes a circular-arc sector that enables a pitch range from -11.0° to 19.0° at a rate of up to 4° per second. Its strut incorporates a roll drive with a range from -170° to 180° at a typical rate of up to 4° per second which, in conjunction with the pitch of the strut, is able to provide angle-of-attack (alpha) and angle-of-sideslip (beta) data. The arc sector's design loads are:

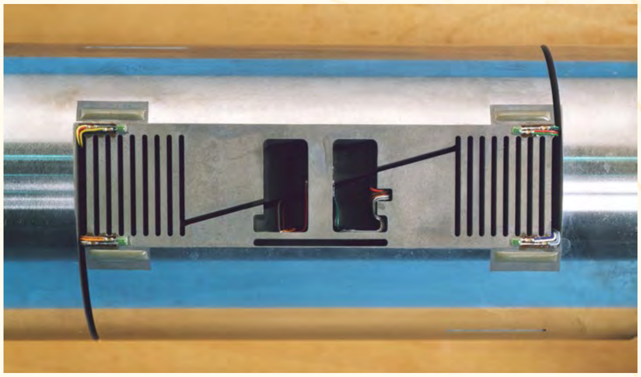
- Normal Force - 19,500 pounds (86,740 Newtons)
- Axial Force - 9,356 pounds (41,617 Newtons)
- Side Force - 10,000 pounds (44,482 Newtons)
- Pitching Moment - 26,000 inch-pounds (91 Newton-meters)
- Rolling Moment - 15,600 inch-pounds (55 Newton-meters)
- Yawing Moment 15,600 inch-pounds (55 Newton-meters)

In general, nominal access to models is 20 minutes in air mode and four hours in cryo mode (wherein Tt = -250°F), with the bulk of the cryo cycle time attributed to conditioning the model to a "hands-on" working temperature.

These times may vary slightly due to model configuration or sizing.

State-of-the-Art Balances

In order to measure three-dimensional model forces and moments in the NTF, a series of special balances have been designed with materials that are robust and able to withstand thermal stresses at cryogenic temperatures. These balances can accommodate the full spectrum of NTF testing – covering both full-span and semi-span test capabilities – and are typically selected based upon anticipated model aerodynamic loads provided by the customer.



In general, internal balances used for full-span or three-dimensional testing are rated for use across the entire air and cryogenic testing envelope. The semi-span balances make use of the "hot balance" concept, wherein the ambient temperature is maintained with heated, re-circulated gas in the semi-span balance enclosure.

All balances are periodically calibrated to their maximum loads to NIST-traceable standards. Check loads are typically applied to the fully assembled model before and after the model has been installed in the wind tunnel, in order to verify instrumentation integrity and to check for deflection-induced fouling.

SYSTEMS and EQUIPMENT

The inventory of available balances is:

Balance	Size		Loads						Cryo Rated
	Max. Dia (inches)	Length (inches)	NF (lbs)	AF (lbs)	PM (in-lbs)	RM (in-lbs)	YM (in-lbs)	SF (lbs)	
NTF-102	2.00	14.281	3,000	600	6,000	600	600	300	Yes
NTF-103	2.00	14.281	1,500	300	3,000	300	300	150	Yes
NTF-104	2.00	14.281	3,400	300	10,000	5,000	5,000	1,000	Yes
NTF-104B	2.00	14.281	3,400	300	10,000	5,000	5,000	1,000	Yes
NTF-105	2.00	14.281	2,000	175	6,000	3,000	3,000	700	Yes
NTF-106	1.75	12.176	2,500	350	5,000	2,500	4,000	1,000	Yes
NTF-107	.75	7.25	160	50	250	100	125	80	Yes
NTF-108	1.50	12.013	1,600	125	3,000	1,500	1,500	500	Yes
NTF-109	3.00	22.4	1,200	175	3,000	900	1,500	350	Yes
NTF-111	1.75	12.176	1,000	300	2,000	1,000	2,000	500	Yes
NTF-112	1.25	9.4	600	180	1,700	1,000	400	280	Yes
NTF-113B	2.37	15.565	6,500	400	13,000	9,000	6,500	4,000	Yes
NTF-113C	2.37	15.565	6,500	400	13,000	9,000	6,500	4,000	Yes
NTF-114S	16.00	25.75	6,100	1,000	70,000	350,000	76,000	n/a	Yes
NTF-117S	16.00	25.75	12,000	1,800	90,000	669,000	100,350	n/a	Yes
NTF-115	1.75	13.881	3,200	200	6,500	4,500	2,500	1,000	Yes
NTF-116A	4 x 3.6	13.75	10,000	700	40,000	16,000	24,000	4,000	Yes
NTF-118	2.38	15.565	6,500	700	13,000	9,000	6,500	4,000	Yes
NTF-119	1.13	10	300	120	800	200	800	300	Yes
729	2.00	12.022	2,500	300	3,500	2,000	2,000	500	No
1621A	2.00	12.022	3,000	500	10,000	7,500	4,500	1,800	No
1621B	2.00	12.022	3,000	500	10,000	7,500	4,500	1,800	No
838	2.00	12.022	3,000	250	7,500	2,500	2,500	1,000	No

Transforming the balance measurements into usable aerodynamic coefficients requires integration of the balance orientation angles with its temperature, temperature distribution and pressure, as well as other situation-specific properties.

Models and Model Support Hardware

NTF can accommodate a wide variety of models and model design/fabrication techniques. For non-cryogenic testing (T≥-50°F), models can use standard construction materials such as aluminum, carbon steel, titanium, etc. When testing cryogenically (T<-50°F), care must be taken with respect to material selection. Maraging steels such as A-200, A-250 or A-286 Vascomax or Nitronic stainless steels are preferred.

After model build-up and prior to tunnel installation, the model is subjected to the thermal environment that will be experienced during testing in a specially designed chamber to validate the model and instrumentation integrity. By identifying and rectifying any anomalies, this pre-test procedure streamlines pre-test processing and reduces risk during testing phases. NTF personnel can make the necessary recommendations to meet all test needs.

NTF maintains an inventory of model support hardware uniquely adapted to the load and temperature test environment of a pressurized cryogenic test facility. Support-sting selection takes into account several criteria to ensure a structurally robust mounting method while minimizing sting interference on the model and data. Stings are tailored to the model, the model instrumentation, and the tunnel. Sting length, the minimum and maximum diameter, and the shape (straight, bent, flat, etc.) can be varied based upon test program requirements.

Additional information on model design and material selection is contained within publications LPR 1710.15, "Wind-Tunnel Model Systems Criteria," and NBSIR 79-1624, "Materials for Cryogenic Wind Tunnel Testing."

Model Protection Safety System (MPSS)

The NTF can be operated at high dynamic pressures, and as such, the model can experience large static and dynamic loads. Although most models are structurally supported by wind tunnel balances to the sting and arc sector, mechanically speaking, the balance may be the weakest structural element in the tunnel. It takes the brunt of full-model loads, experiencing large dynamic loads caused by model balance-sting elastic modes varying from 6 Hz to 40 Hz. If damping remains low, this dynamic oscillation can be significantly larger than the static loads, as in the case of wing stall.

An NTF Model Systems Stress Engineer will review the customer's model design attributes (stress report), along with the balance/sting/support system capacities, and develop test operations safety criteria identifying any limitations that will be monitored throughout testing.

The MPSS is a stand-alone system operating independently of the NTF's data acquisition system, dedicated to the task of model-load safety. It has a dynamic, precision load-measuring instrument that continuously monitors the wind tunnel balance's unfiltered raw loads, and is device-capable of 0-40Hz response. The MPSS takes the raw, unfiltered signals from six channels and processes them to remove interactions between channels at high speeds, and then compares the instantaneous load with a set value to determine safe-load, alarm, or unsafe-trip-level conditions.

The MPSS will issue an alarm when any balance channel exceeds 90% of the limiting load, and a trip command at 100% of the limiting load. The test operations safety criteria iterated above are the inputs for the MPSS, and records and archives a 24-hour log of all loads.

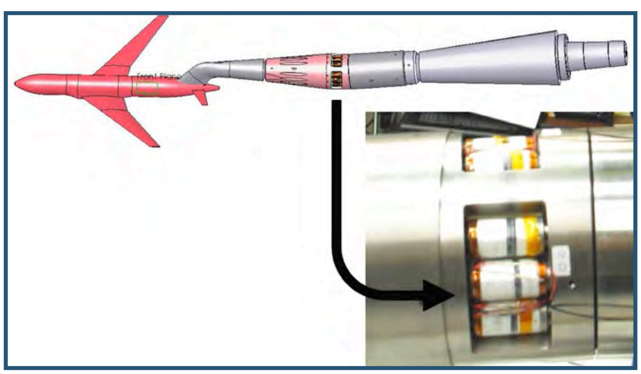
The MPSS also has a modal analysis component that provides real-time spectral data from balance loads. It can be set to identify wing buzz, buffet, and other aerodynamic instabilities, and use them to safe tunnel systems if a critical load limit is reached.

This system has been upgraded in 2012 to incorporate a digital signal processing capability that provides 100% signal tracking at the test sampling rate. It duplicates all of the functions of existing MPSS with higher bandwidth and no loss of signals with an improved dynamic response from 30 to 500 Hz. It can also utilize the “Modified Goodman” algorithm. The Goodman algorithm separates the static load effect from dynamic load, weighing the static and dynamic components differently and generates a method of mixing the two to arrive at a safe loading boundary. With this method, higher test conditions (dynamic pressure, angle of attack, etc.) may be possible.

Model Dynamics Damping System

To reduce the amount and magnitude of aerodynamically induced model dynamics, a model dynamics damping system was developed and has been deployed in the NTF. The basic principle and function of the damper is to generate a dissipating energy based on the stored energy in the sting. The active system is capable of doubling the angle-of-attack range (model-configuration dependent) during testing by reducing dynamic loads precipitated by wing buffet or post-stall aerodynamics.

The system consists of 12 11,000-lb (48,930-N) piezoceramic actuators made of lead zirconate titanate. Four groups of three actuators are orthogonally placed around the base of the sting; each is driven by wide-band drive amplifiers. The actuators are heated to maintain full dynamic damping capacity throughout the entire NTF operating envelope.



Pressure Measurements

Depending on accuracy requirements, steady-state pressure measurements in the NTF are made with several different types of instrumentation.

The Mach Measurement System (MMS) is designed to measure tunnel total and static pressures such that the resulting Mach number accuracy is ±0.0005 over a Mach range from 0.2 to 1.2. This system consists of two different absolute pressure ranges and two different differential pressure ranges, each to span the entire operating pressure envelope of the NTF.

The MMS consists of Fluke bourdon tube sensors that are high-line-pressure capable, and whose ranges are 150 PSIA and 55 PSID for the “main” MMS, plus a, 50 PSIA and 14 PSID “low” MMS. A pressure-monitoring system provides automatic over-pressurization protection at 90% of full scale.

The gauges for this system have a laboratory quoted accuracy of ±0.009% of reading, and the sensitivities of the transducers are determined by off-site laboratory calibrations. Two-point in-place characterizations are made daily.

For multi-channel applications – such as measurements on the test section walls and on models with multiple pressure orifices – electronically scanned pressure (ESP) instrumentation is used.

The ESP system consists of several key components. The multi-transducer modules – available with 16, 32, 48 and 64 ports – are housed in thermal enclosures in the NTF cryogenic environment, with the temperature maintained at near-ambient levels to minimize electrical drift. Through the combination of the remote power supply and the scanner junction unit (SJU), the modules are interfaced with the system processor that contains the scanner digitizing units.

The small size of the SJU allows the transducer voltage to be controlled at or very near the model. This unit is also housed in a thermal enclosure. The modules are pneumatically connected to the model orifices, the tunnel reference pressure, the local processor with its slot-mounted pressure calibration units, and the bias control unit. This unit biases the control line pressure – shifting the module to run/calibrate position – to valves that are approximately 100 PSI above the tunnel reference pressure.

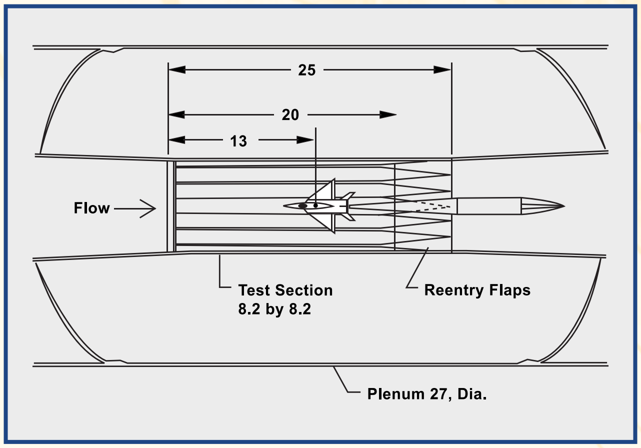
At the NTF, this system is configured such that the host computer commands the ESP system to read/send raw voltage at a prescribed scan rate over a specified period of time. This period of time is the same acquisition period used for other types of data such as balance data and tunnel parameter data. The maximum scan rate is dependent on the total number of ports being measured. The average voltage from each module is converted to engineering units.

During calibration of the ESP system, online diagnostics are used to indicate that the system is performing correctly and within expected tolerances. In order to check the ESP system(s) during tunnel operation, at least one port on each module is pneumatically connected so that the differential pressure will equal zero for that port. When the indicated pressure on that reference port exceeds the accuracy tolerance (% FS), a zero calibration is usually performed.

Angle Measurements

High-resolution angle measurements (angle of attack, or AoA) are vital to developing accurate data sets. Models are typically configured with an AoA package that houses two single-axis accelerometers and two 2-axis accelerometers for sting whip. These devices are calibrated using an angle measurement system (AMS) developed at NASA Langley. The AMS was originally developed to check taper fits in the wind tunnel model support system.

The system was further developed to measure simultaneous pitch and roll angles using three orthogonally mounted accelerometers (3-axis). This 3-axis arrangement is used as a transfer standard from the calibration standard to the wind tunnel facility. It is generally used to establish model pitch and roll zero, and performs the in-situ calibration on model attitude devices providing angle measurements to within 0.001°. The reference used in calibrating the AMS is a high-accuracy 2-axis indexing head capable of setting angles to within 0.0004°.



Pitch System

The NTF allows pitch control from –11 to +19 °, and roll of +180 to –170 °.

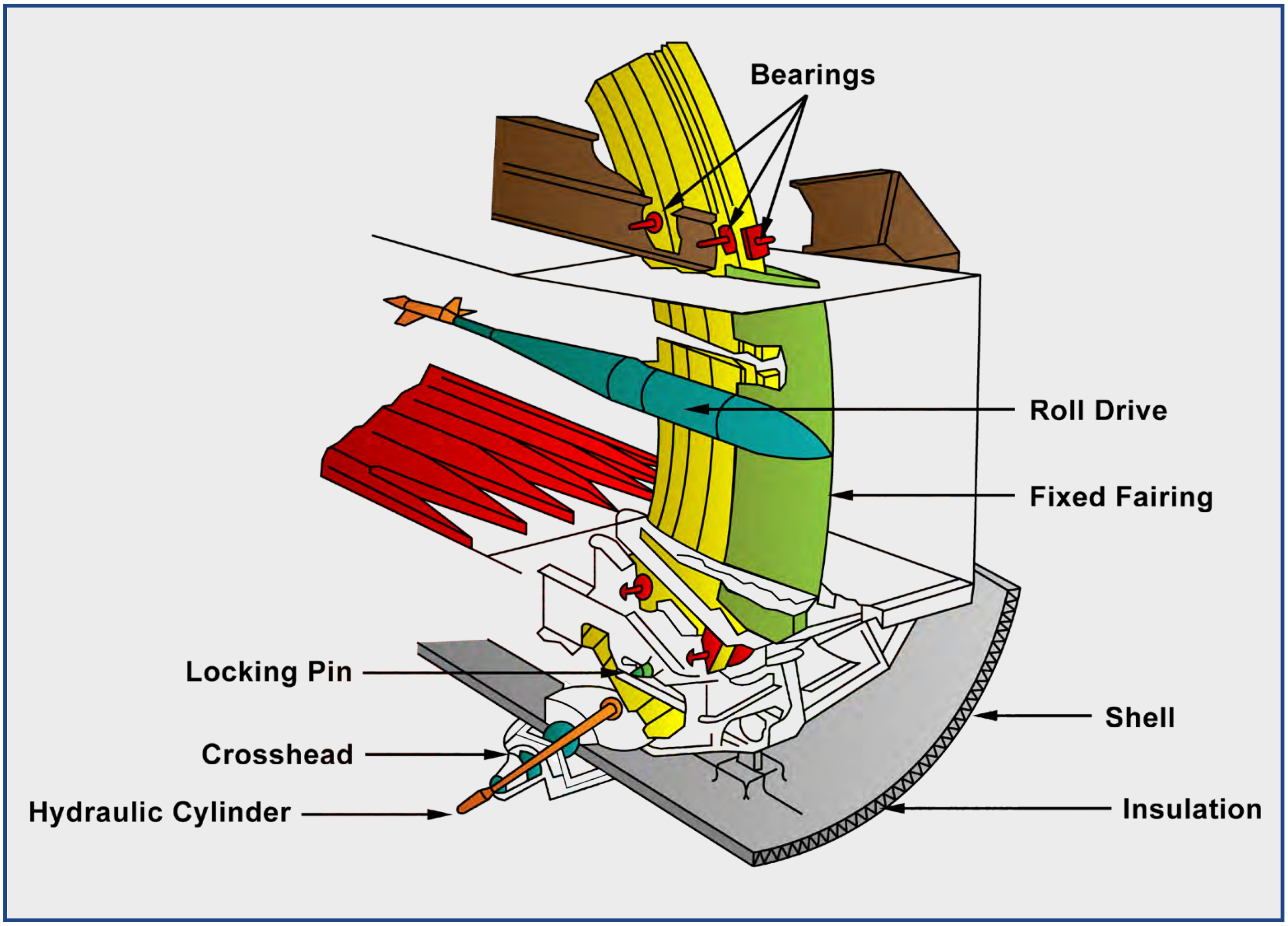
The NTF arc sector is a five-inch thick plate about 275 inches long, with a chord of 60 inches, and supported over a span of 150 inches. The inner edge moves in a radius of 150 inches, with the model located at the center. To obtain the pitch range of -11 to +19 °, it is raised/lowered a total of 120 inches. The center of this sector is a hollow cylinder along the tunnel flow axis. It houses the roll drive mechanism with a fairly massive roll drive shaft, as well as the wiring terminal box known as JB16.

The arc sector has a center-of-rotation radius of 190 inches. With proper sting length selection, models are installed very close to this center-of-rotation point to keep them in the center of the test section throughout their angle-of-attack range, minimizing vertical translation in the test section.

The arc sector slides between four preloaded, self-aligning Vespel pucks that provide adequate lateral stiffness. Axialthrust pucks support the drag load on the model-arc sector system in the flow axis.

Driving the hydraulic actuator are two servo-controlled hydraulic systems, operating at 2,000 PSIG. The inching pump is capable of 0.25 deg/s motion, and a more powerful hydraulic system that can move the arc sector at up to 4° per second is typically used during wind-on testing.

All model sensor wires are terminated at JB16, which moves with the arc sector. The wiring from JB16 to the tunnel control/data room is through a take-up wiring loop. As the arc sector moves, the take-up loop of wire allows an up-and-down motion of the arc sector (including JB16) without straining the wires.



SYSTEMS and EQUIPMENT

Roll System

The NTF roll drive is a closed-loop DC motor type control system with potentiometer feedback, and resides in the arc sector. The model support stings are attached to the rotor of this motor. All of the model instrumentation cables and pressure tubes are channeled through the hollow center of the roll mechanism.

Although the roll drive rate is typically set to 4 ° per second, the maximum value is greater and can be "throttled" for test-specific requirements. The total roll stroke is 350°, running from +180° to -170°.

The NTF model support system cannot physically yaw the model; a combined pitch-and-roll angular-rotation sequence will provide an aerodynamic yaw with respect to wind vector (angle-of-sideslip or beta).

Sidewall Model Support System

The NTF can also conduct semi-span model investigations using the Sidewall Model Support System (SMSS). The SMSS is installed in the test section wall with the model mounted on the test section horizontal centerline. The SMSS has a ±28° pitch capability, and can accommodate 5-component strain gauge balances up to 27,000 lbs (120,102 N) of normal force.

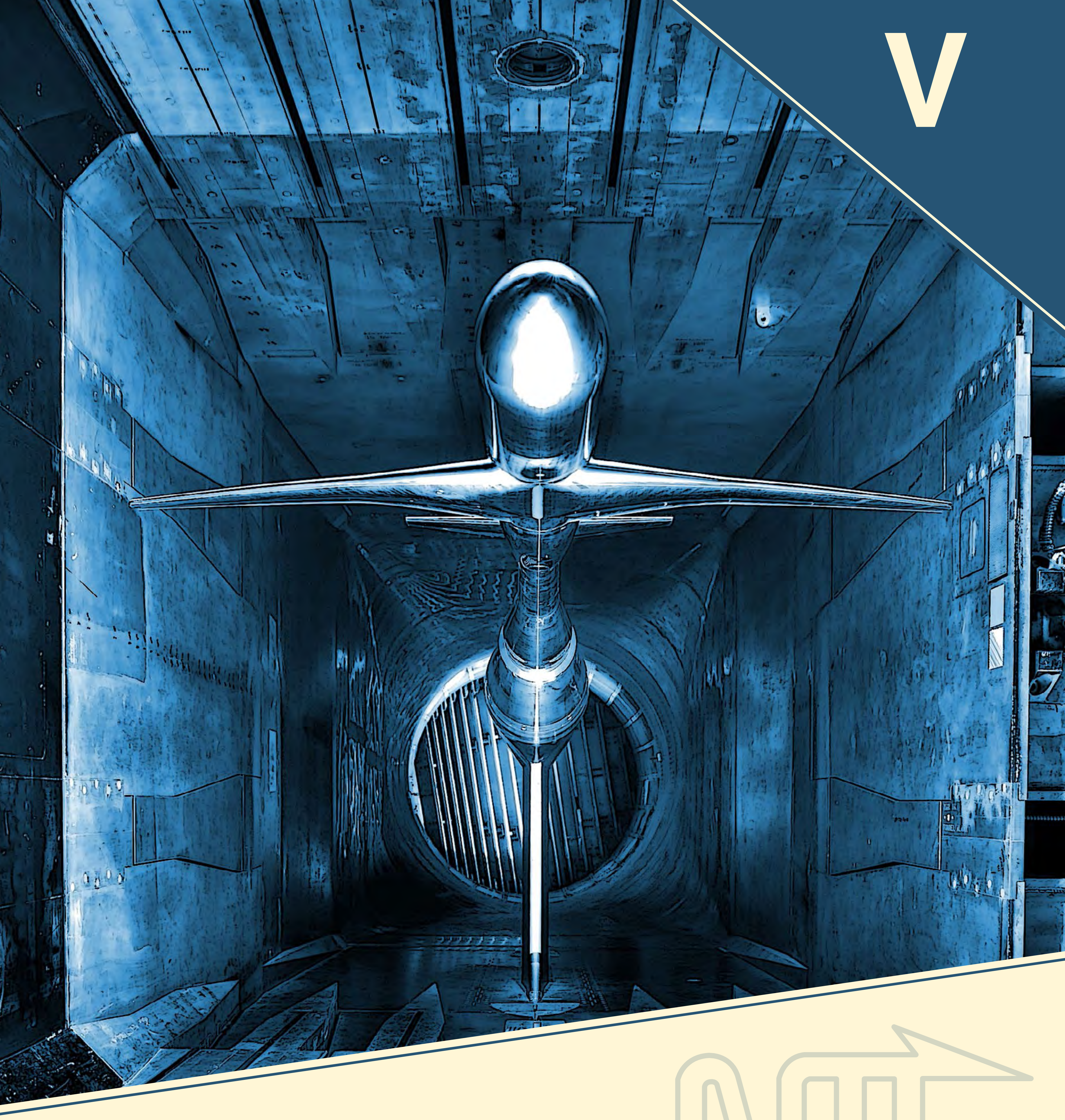
The model is attached via adaptive hardware to the balance, which is installed behind the test section wall within an insulated and heated enclosure. The SMSS can also accommodate a dual-channel, high-pressure air system to support propulsion airframe integration studies, circulation control high-lift concepts, powered lift, and cruise or separation flow control. The SMSS is rated for the lowest cryogenic operating temperature of the NTF of -250°F (-157°C) however when the dual channel high pressure air system is utilized, the system is limited to -50°F (-46°C).

To minimize thermally induced balance stresses, the SMSS uses a hot-balance concept whereby the balance is regulated to a constant temperature of 100°F (38°C) even though the model may be exposed to cryogenic temperatures of -250°F (-157°C). Since the balance force-moment data are influenced by the balance temperature gradients, it is essential to maintain a constant and homogenous balance temperature.

A blower-heater system regulates the SMSS cavity temperature with a 10kW heater to maintain a constant balance temperature of 100°F (38°C). Due to the mass of the balance and the responsive re-circulating system, the balance temperature remains very stable once equalized. Balance temperatures are typically held to within ±1°F (0.6°C) during testing operations. The balance cavity pressure floats with the tunnel pressure.

In addition to the blower-heater system, the SMSS has a number of other surface heaters in strategic locations within the pitch system and instrumentation cavities. These heaters are used to maintain a temperature between 50°F and 100°F (10°C and 38°C). Temperature control in these areas does not have to be very tight since these heaters are meant only to keep the carbon steel bearings, gearbox oils, and other components from freezing.

V



DATA ACQUISITION / REDUCTION

V - DATA ACQUISITION / REDUCTION

The NTF data system offers exceptional data collection characteristics for customers. The facility provides data reduction in real-time and offline modes.

The real-time process must interact with the NTF process control activities for safety and control functions. The off-line data-reduction process contains a few data correction types not implemented in the real-time process, such as wall interference corrections.

Real-Time Systems Group

The NTF's Open Architecture Data System consists of three data acquisition/reduction systems in the Real-Time Systems (RTS) group:

- The Research Computer System (RCS), the Process Computer System (PCS) and the Model Preparation Area (MPA)
- A Host Computer System (HCS)
- Networked Display System Consoles (NDSC)

Together, these computer systems provide the functionality for acquiring, processing, recording, and displaying online and offline data from the model, the tunnel, and the model preparation areas.

The Personal Computer (PC)-based Data Acquisition Software (DAS) operates using industry standard Windows® 7 (64-bit requirement) operating systems and utilizes the Jacobs Technology Test SLATE (Software for Laboratory and Automated Test Environments) software. Test SLATE is a powerful, versatile, general purpose test control and measurement application that enables NTF to quickly and intuitively create a custom data acquisition and test automation program without programming skills, using the simple, point-and-click, Windows® 7-based graphical user interface. Test SLATE enables NTF to quickly create sophisticated automated test sequences with "if-then-else" functionality.

The RCS/PCS DAS includes 15 user workstations. Three PCs are used for Master Operations Consoles (MOCs), 11 PCs (two of which are laptops) are used for Auxiliary Operations Consoles (AOCs), and one AOC PC is a spare. Each user workstation (RCS/PCS, and MPA) is capable of supporting two or more monitors. One roll-around desk-type computer station is used for the MPA.

The user workstation computers contain 4GB of memory (expandable to 24GB), have standard DVD/CD-ROM R/W capabilities, support video resolutions of 2,560 x 1,600 or more, support two redundant arrays of independent disks (RAID) 1/0 SATA data drives of at least 500GB capacity, support four USB 2.0 interfaces, and have a Quad Core Intel® Xeon® W3520 2.66GHz, 8M Processor or better.

The Data Processing Server PC is network-server class, and contains two quad-core processors, at least 8GB of memory, expandable to 128 GB of memory, and two RAID 1/0 SATA data drives of 1TB capacity in a rack-mount configuration. The DAS RAID storage system and LT04 tape backup systems are connected to this Data Processing Server.

The DAS provides a centralized RAID rack-mounted storage system with 20TB of removable media for local data storage.

The NTF DAS has the ability to define test sequences that automate the control of the model attitude and recording of the acquired data. This feature supports both pitch/pause and continuous-sweep data acquisition. For the pitch/pause or continuous-sweep modes of operation, at least 1,000 test matrix entries can be programmed. Also provided is the ability to define the next configuration or test schedule matrix without affecting the current test scheduling. The Automated Test Sequencer operates in concert with the RCS and the PCS.

The PCS data acquisition subsystem is responsible for collecting data from several different data acquisition units (DAUs). The primary analog inputs consist of a Neff

620/500 controller and a Neff 620/600 analog input subsystem with up to 256 analog channels and 16 digital channels.

Other analog inputs come via a serial RS-232 interface from a PC-based temperature monitor scanner system that tracks up to 640 temperatures for tunnel safety and structural integrity assessment. Three sequencers, consisting of programmable logic controllers (PLCs) that control and sequence tunnel interlocks, transmit up to 4,096 discrete digital state inputs to the PCS.

The PCS also receives data over a high-speed SCRAMNet reflective memory system. These data come from three control microprocessors and from the RCS system, some of which are used to control model attitude.

State-of-the-Art Alarm System

Since safety is paramount at the NTF, the PCS has an elaborate alarm system. This system provides a channel-based alarm processing capability, providing an independent configuration for each channel in the test setup file. When a channel enters or exits an alarm state, a message is logged to the alarm display window, the system log window and the system log files.

A channel can also be configured to activate visual and/or audible annunciators. These annunciators are located on the Test Engineer's panel, and their on/off status is controlled by the alarm system software. Each channel has a deadband parameter that reduces unwanted alarms, without affecting safety. Optionally, a response procedure can be displayed for corrective action.

Time Stamping

The NTF DAS provides a high-precision, referenced time base for real-time "time stamping" of all data sources to allow for online, offline, and post-test time correlation of data. This Global Positioning System (GPS)-based time source is referenced to Universal Coordinated Time and provides synchronization of all DAS system clocks to within ± 500 nanoseconds.

This same time source is clocked into the Neff Instrument Systems via Wyle Digital Input Adapters, and captured as a component of each analog input scan.

An Inter-Range Instrumentation Group (IRIG) time [IRIG B, A132] is supported in the NTF DAS. Each major subsystem (Neff, PSI8400, digital video, etc.) has the necessary hardware and software for time-stamping data.

All NTF DAS data are time stamped to allow for data time alignment within the Data Reduction Software (DRS). The Test SLATE software provides a time-lag value for each tag that is stored with the tag data. The time-lag value represents the lag time of that channel's measurement lag-time with respect to a reference time stamp mark.

This time-lag value and the tag time-stamp data allow for the adjustment and correlation of data for differing data measurement lag times at various tunnel conditions, thereby facilitating conditional sampling methods, continuous sweep data collection, and data analysis.

Data Collection and Analysis

The RCS data acquisition subsystem collects data from a similar Neff DAU containing 256 analog channels and 16 digital channels. This system continuously acquires, computes, performs alarm checks, and displays model data and tunnel parameters. The RCS computer also receives model and tunnel wall pressure data from an electronically scanned pressure system (ESP 8400) across an IEEE 488 interface.

Standard force and moment data are measured with strain gauge balances calibrated to account for first- and second-order interactions. Corrections for temperature, pressure or other effects can also be incorporated into the balance calibration matrix. Other measurements may also be made, such as pressures from the model, tunnel walls, boundary-layer rakes, internal flow rakes, and wing gauges.

Model angles are measured with either an on-board accelerometer package or the accelerometer located in the arc sector. Model roll angle is measured by either a resolver or potentiometer. Since NTF is a cryogenic wind tunnel, temperatures are monitored in many regions of the tunnel and on the model. The RCS computer also processes data from thermocouples, platinum resistance thermometers and various other temperature-measuring devices.

The ESP 8400 front-end system supports 1,024 Digitally Temperature Compensated (DTC) channels, and includes the NASA LaRC standard ESP 8400 data acquisition and PSI averaging modes. The DAS supports scan rates of 0 to 50 frames/second for the ESP 8400 in the single frame data acquisition mode. Scan rates of 0 to 100 frames/second for the ESP 8400 are supported in the frame data accumulation and averaging mode. The ESP 8400 scan rate is independent from the Neff scan rate.

During operation, two tasks run in the RCS computer: The TCYCL acquires, averages, reduces and displays cyclic or real-time data, and the TPOINT acquires, averages, reduces, records and displays static (point-based) data.

A Dynamic Data Acquisition System (DDAS) is also available and is an integral part of the facility's research data collection process on RCS. The DDAS can collect data at selectable sample rates (up to 5 kHz) on 32 analog channels with 24-bit resolution, and allows real-time spectral analysis up to 512 Hz.

Pre-Test Setup

Three model preparation areas (MPAs) are available and can be used for pre-test setup to minimize the time required for model installation and instrumentation verification. The MPA data acquisition sub-system is patterned after the RCS and runs a subset of the RCS software. It is used for accelerometer calibrations, balance loadings, weight tares, balance residual checks, sting-deflection calibrations, and pressure-orifice leak checks.

Following model assembly and ambient temperature checkout, cryogenic models undergo further checkout in the cryogenic chamber located in MPA 3. The data acquired during the cryogenic checkout is later used for balance temperature corrections during the actual tunnel test.

Neff 620/500 Controller Features and Functions

As previously noted, each of the RTS computers interfaces with the Neff 620/500 controller and the Neff 620/600 DAU to acquire analog and digital data. The Neff 620/600 is a high-speed unit that measures multi-point, low-level and high-level analog signals. This unit provides the system with the following features and functions:

- Analog-to-digital conversion
- 16-bit resolution (including sign)
- Accuracy of 0.02% of full-scale microvolt range at constant temperature after auto-calibration
- Programmable gain post amps with steps 1, 2, 4, 8, 16 and 32
- Auto-ranging capability with throughput of 50 kHz (currently used on fixed range)
- Maximum throughput of 190 kHz
- Automatic zero and full-scale calibration
- Precision internal voltage calibration source
- Alphanumeric display for viewing channel values online and offline

The Neff 600 unit uses the Neff 620650 amplifier/filter circuit cards to signal-condition the incoming data signals before they are digitized. Each card contains four channels and has the following features and functions:

- Programmable gain preamps with steps 1, 8, 64 and 512
- Programmable filter selection, using 4-pole Butterworth low-pass filters, with steps of 1, 10, 100 and 1,000 Hz

- Full-scale voltage ranges, from 5 millivolts to 10 volts
- Input protection of 100 VDC or peak AC
- Common range rejection ratio of 66 dB to 120 dB, depending on gain and filter settings
- Buffered wide-band output available for each channel for external use

One of the capabilities of the Neff 620/600 is automatic internal self-calibration for all data channels (defined in the acquisition setup file) using all gain and filter steps available. Zero-scale and full-scale corrections are determined for each channel. This information is stored in the Neff internal calibration memory, written to calibration disk files, and, if enabled, also written to the test recording file (i.e. a raw-data file). Both the number of scans and the averaging period is configurable.

Tunnel-related information is often used by both the operations staff and the research engineer. Since the PCS and RCS are on a local area network, information can be passed back and forth, and mixed on displays and plots. This is helpful during cryogenic and/or high-pressure operations, since the tunnel environment affects the quality of the research data.

The outputs from pressure gauges and thermocouples located throughout the tunnel are recorded on the PCS system and, if desired, can be displayed along with the model data from the RCS.

Model and Tunnel Wall Pressures

Depending on the accuracy requirements, steady-state pressure measurements in the NTF are made with several different types of instrumentation.

As previously detailed, for multi-channel applications such as measurements on the test section walls and on models with multiple pressure orifices, ESP instrumentation is used. Tunnel wall pressures (16 rows for a total of 352 orifices) can be measured and used to make wall interference assessments. The orifice layout and the standard module hook-up remain essentially the same from test to test.

Real Gas Effects Correction

With the possibility of using air, gaseous nitrogen, or some mixture of these two gases as the testing fluid, the NTF employs the Beattie-Bridgeman equation of state as the basis for calculating the various unmeasured flow parameters. This equation of state expression and solution method is an attempt to accurately model real gases by going beyond the ideal gas equation.

With measurements of free-stream total pressure, total temperature and a static reference pressure, the other important reference conditions such as Mach number, Reynolds number, and dynamic pressure can be calculated by using the Beattie-Bridgeman thermodynamic equations. These equations express properties such as entropy, enthalpy, specific heat, and speed of sound in terms of the equation of state, its derivatives, and the ideal gas-specific heat values.

Using these equations – along with the assumption that the flow is isentropic (constant entropy) and adiabatic (no heat transfer) – allow the use of an iterative solution of the adiabatic energy equation $HT = H + (V^2/2)$, where H is enthalpy and V is velocity. Once this solution is complete, all of the desired reference quantities can be calculated.

NTF's Offline Data Reduction Process

The NTF offline data reduction program, RCSDR, is a variant of the real-time data acquisition/reduction code system, and is used to process data in an offline environment. Efforts have been made to keep the real-time REALT and offline RCSDR reduction codes as similar as possible.

One of the primary differences between the offline RCSDR reduction program and its real-time counterpart is that the RCSDR processes raw files, whereas the real-time software processes recently acquired raw data: a difference only in the data source and the logistics associated with the real-time environment.

Both modes of reduction use setup files to define pertinent parameters, or to define the paths the reduction process needs to take.

The RCSDR is essentially a collection of algorithms acting sequentially under the control of the input specifications – taking the original recorded raw-channel measurements and supplied constants for each data point through a series of ordered transformations and corrections – until a final set of fully corrected aerodynamic coefficients has been calculated.

Normally, any test-specific computations are implemented only in the offline reduction process. In addition, there are also some types of data corrections that are only done in the offline environment. Therefore, the offline reduction results are those that can be considered fully corrected and final. There are also corrections (wall interference corrections, or TWICS) that, at present, are done after the offline reduction process has been completed.

Data Security

NTF and the NTF DAS system are capable of supporting classified and customer-proprietary testing (e.g. physical hardware security and software security) as defined by NASA LaRC policy. Data is stored in a centralized location such that the data may be removed (secured) from the Control Room during and after a secure test. No customer test data or configuration data is permanently stored in any location other than the centralized storage system.

NTF Flow Visualization

Video Model Deformation System (VMDS) - The VMDS has evolved from a special test technique, used occasionally, to a measurement capability requested for almost every test. Wing twist, flap deflections, wingtip deflections and others are now within the scope of this optical measurement technique. The system has been enhanced with high-resolution digital cameras and precision-pointing hardware with remote pan/tilt capability.

To utilize this measurement technique, small 0.250-inch diameter (6.35 millimeters) targets that average 0.001-inches (0.025 millimeters) thick are painted on the surface of the model. By subtracting wind-off reference images from the wind-on images, twist and deflection measurements can then be obtained through photogrammetry. Thermal effects require that very low Mach number wind-off polars be obtained during cryogenic model testing.

Schlieren Systems - The sharp-focusing Schlieren System has been historically used as a diagnostic tool to support analysis of test-section and model-flow characteristics suggested by other indicators. Typically, it can visualize shock locations span-wise to approximately 2 inches (50 millimeters). Imagery is available at a sample rate of four frames per second.

The NTF also utilizes a retro-reflective Background Oriented Schlieren (BOS) method to visualize off-model flow characteristics. BOS simplifies the visualization process by eliminating the need for the use of expensive mirrors, lasers and knife-edges. BOS makes use of simple background patterns of a randomly generated dot-pattern (paint dots), a high-intensity light source, and high definition digital cameras. A baseline wind-off image when compared to the wind-on images allows for the visualization of shock waves and expansions due to refraction index gradient changes in the flow.

Video Fluorescent Minituft Flow Visualization System - Minitufts can be used to visualize flow over the model surface. Recent adaptations have improved the durability of the material. Continuous-wave, light-emitting diode (LED) lighting in lieu of normal flash illumination has enabled real-time monitoring of model-surface flow. However, while small, the minituft material [0.0027 inch (0.069 millimeter) monofilament] used with the VFMFVS may affect the flow over the model at the high Reynolds numbers achievable in NTF testing.

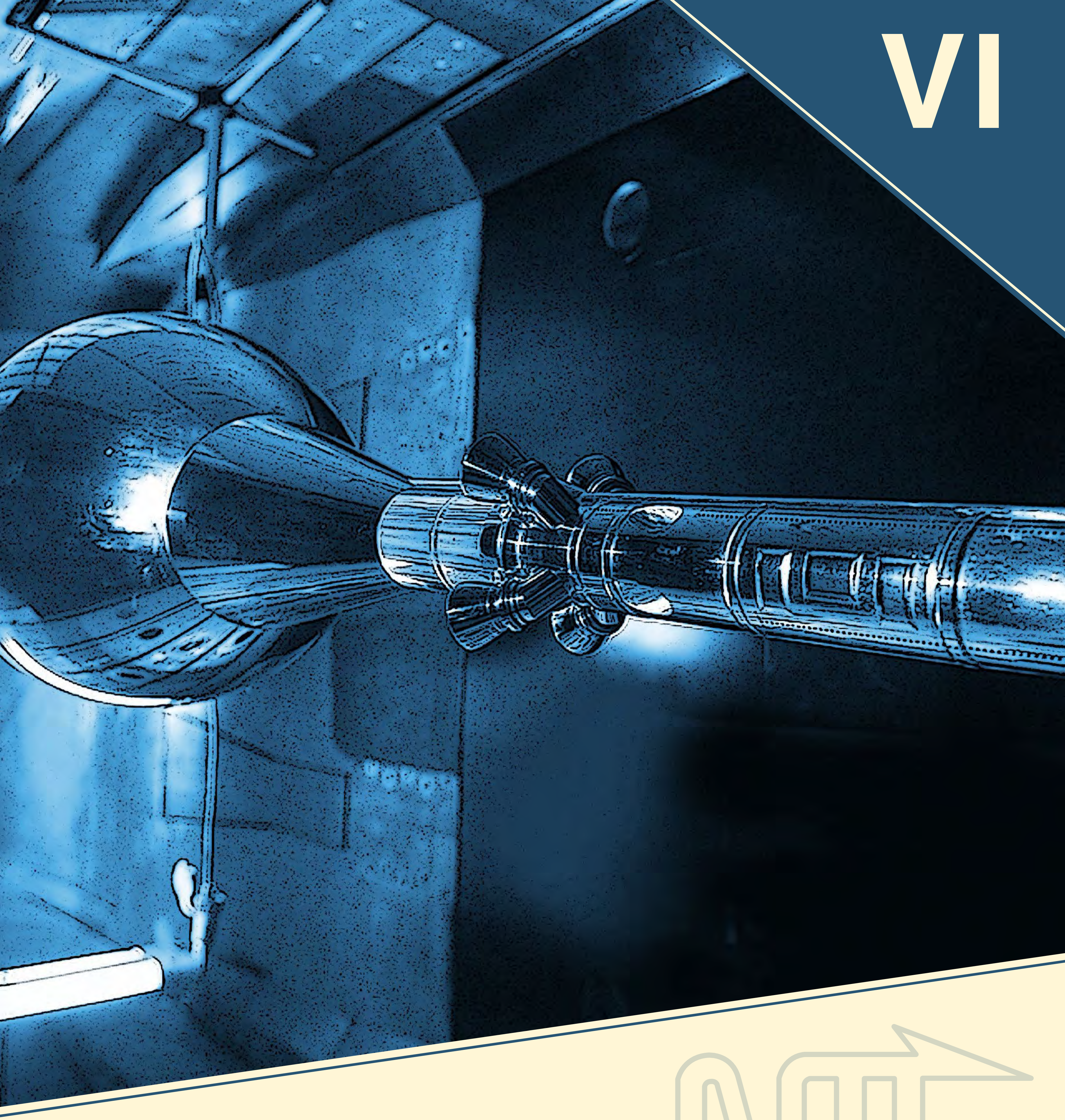
Pressure/Temperature Sensitive Paint (PSP/TSP) System - The PSP/TSP system is used to visualize and measure model global-pressure distributions, and to visualize laminar-flow transition. The system has been updated recently to include higher-resolution imagery (4,000 by 2,500 pixels) with improved LED illumination. These test techniques can be used throughout the normal temperature range of the tunnel, namely 120°F to -250°F (49°C to -157°C).

The PSP technique in cryo mode typically requires air injection into the tunnel to achieve a minimum oxygen level of 1,500 parts per million. The paint application is considered non-intrusive because its thickness is typically on the order of 0.003 inches (0.076 millimeters), and finished to an approximate surface roughness of 10 microinches (0.0003 millimeters).

To prevent the paint from "tripping" the flow, the coating should be applied around the leading edge of the model. When used on a model with static pressure orifices, this technique will generally require purging through the pressure ports with air to prevent them from clogging during paint application. Special ESP modules with purge capability are available to provide this function. Paint is typically applied by experienced facility personnel.

Sublimation Flow Visualization System - To detect laminar-to-turbulent transition locations, dye-sublimation flow visualization is available for testing at temperatures from +40°F to +120°F (4°C to 49°C).

Fluorescent Oil Flow - This technique has been successfully applied over a tunnel test temperature range of +40°F to 120°F (4°C to 49°C). However, use of this technique will contaminate the tunnel with fluorescent dye that will subsequently have to be remediated at the conclusion of the customer test program.



VI

NOTABLE NTF STUDY DETAILS

VI - NOTABLE NTF STUDY DETAILS

A wide variety of aerospace vehicles have undergone NTF testing and assessment, including studies related to cruise performance, configuration aerodynamics, stability and control, and stall-buffet onset.

Since its commissioning, the NTF has evaluated models of the space shuttle, the space shuttle booster and the shuttle booster stack, the Delta II Heavy Launch Vehicle, the F-18 E/F Super Hornet, the blended-wing-body aircraft, the Grumman X-29 experimental airplane, and even the Seawolf submarine. The facility's ability to obtain near-flight Reynolds numbers has proven essential in accurately predicting aerospace-vehicle behavior under real-world flight conditions.

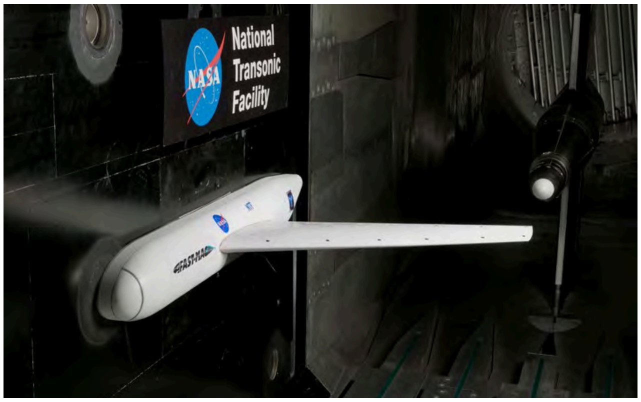
Details of such testing appear below

Orion Multi-Purpose Crew Vehicle (MPCV)

The MPCV spacecraft includes crew and service modules, a spacecraft adaptor, and a launch-abort system. Much larger than its Apollo predecessor, the MPCV can support more crewmembers for short or long-duration missions. The service module is the powerhouse that fuels and propels the spacecraft, stores air and water, and provides space for scientific experiments and cargo.

A 6%-scale MPCV model, including the craft's launch-abort system, was assessed in the NTF to gather launch-related aerodynamic data.

Fundamental Aerodynamics Subsonic Transonic Modular Active Control (FASTMAC) Model



NASA is working with industry, university, and Department of Defense partners to advance the state of the art in prediction techniques associated with circulation control. To better understand the limitations of experimental and computational fluid dynamics (CFD) techniques, researchers are conducting low-speed, physics-based experiments that emphasize off-body measurements.

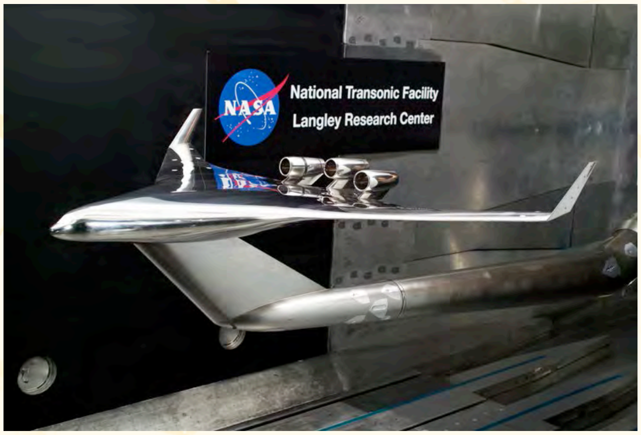
Using the Fundamental Aerodynamics Subsonic Transonic Modular Active Control (FASTMAC) semi-span model, an NTF experiment was conducted to evaluate the effect of Reynolds number on circulation-control aerodynamics, and to develop a FASTMAC open dataset for CFD code validation. The effect of varying the span-wise blowing distribution was also investigated, and cryogenic pressure-sensitive paint data were acquired.

The FASTMAC model was tested in two configurations: low-speed high-lift and high-speed cruise. The effect of Reynolds number on circulation-control aerodynamics was successfully documented during this test, and an open dataset for CFD code validation was created. A significant increase in lift at low speed was measured, as well as a drag reduction at high-speed conditions. Control of the shock on the wing was also successfully demonstrated.

NOTABLE NTF STUDY DETAILS

Blended Wing Body

In partnership with NASA and the Air Force, The Boeing Company tested its X-48 blended-wing-body scale model in the NTF. Advantages of the blended wing-body concept include high fuel efficiency, low noise, and a large payload volume relative to size.



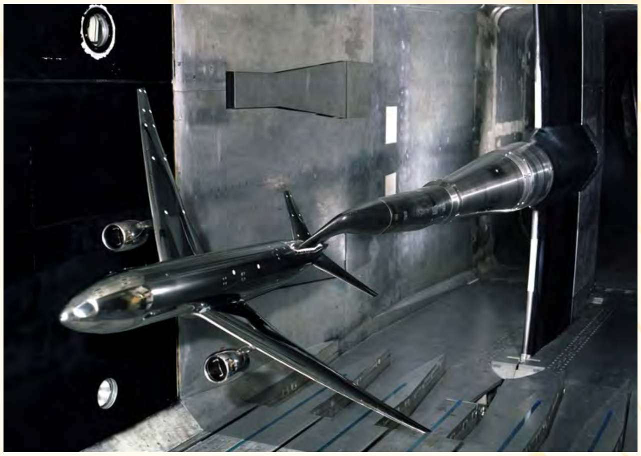
Evaluated at the NTF were potential high-lift system designs – including blended-wing flaps and struts – that would be used to increase lift performance. System studies also indicated that a 10% fuel savings would result from surface-mounted boundary-layer-ingestion engine nacelles, versus pylon-mounted versions. Design methods to eliminate most flow separation were evaluated, and a zonal-design approach reduced design run times by factors of between 3 and 10.

The NTF's unique cryogenic flow visualization was able to confirm the quality of computational fluid dynamics data relating to blended-wing flow separation across the fuselage surface and engine nacelles.

Boeing 767 I 777 I 787

Even small improvements in the performance of an airplane's high-lift system can significantly affect takeoff field length, weight-carrying capability, noise, and range. The NTF has conducted high Reynolds number studies of the complex airflow issues encountered by aircraft when flaps and slats are extended from a wing.

The Boeing Company has frequently used the NTF to test new aviation concepts, including those related to lift. Scale models of the Boeing 767 and 777 have been evaluated in the facility. The latest Boeing test involved evaluating high-lift 787 "Dreamliner" system designs.



To assess its 787 high-lift concepts, Boeing developers designed new trailing edge flaps and fit them to an existing 5.2-%-scale 777 semi-span model. That model was mounted onto the NTF sidewall and tested extensively.

F-18 E/F Super Hornet

A variant of the U.S. Navy's F/A-18 Hornet, the F/A-18E/F Super Hornet is a larger and heavier version, with improved range and payload. Designed and initially produced by McDonnell Douglas, the Super Hornet first flew in 1995. Full-rate production began in September 1997. The Super Hornet entered service with the United States Navy in 1999, replaced the Grumman F-14 Tomcat in 2006, and serves alongside the original Hornet.

During the winter of 1997-98, the Navy asked NASA for assistance in resolving the "wing drop" phenomenon, which caused an abrupt rolling motion of the aircraft during certain flight conditions. Although not a safety-of-flight issue, the roll-offs occurred during high-speed, high-G maneuvers, preventing the pilot from performing close-in tracking maneuvers on potential adversaries.

NOTABLE NTF STUDY DETAILS

Having identified wing drop as a problem in early 1996, the Boeing/Navy team performed wind tunnel tests – in the NTF, among others – as well as computational fluid dynamic studies to identify the root cause. Moderating air-flow-separation differences between the left and right wings proved difficult, and a wide variety of solutions were explored.

During this period, Langley engineers suggested that the flight program apply a NASA-developed technology – passive porosity – to a small section of the upper surface of the wing at the point where the wing folds for aircraft carrier operations. This solution, refined by the NASA and Boeing team, resolved the wing-drop problem and enabled the Department of Defense to authorize continued production of the aircraft.

Grumman X-29

Two X-29 aircraft were flown at NASA's Dryden Flight Research Center to investigate advanced concepts and technologies, such as the use of advanced composites in aircraft construction; variable camber wing surfaces; the X-29's unique forward-swept wing and its thin supercritical airfoil; strake flaps; close-coupled canards; and a computerized fly-by-wire flight control system to maintain control of the otherwise unstable vehicle.

A cooperative effort between Dryden and Langley involved three phases: flight testing, wind tunnel testing in the NTF, and computational support of each experimental phase. NTF involvement led to better understanding of the complex geometries of the X-29's design.

Research results showed that the configuration of forward swept wings, coupled with movable canards, gave pilots excellent control response at up to 45 ° angle of attack. Although the X-29 did not demonstrate the overall reduction in aerodynamic drag that earlier studies had suggested, the program demonstrated the feasibility of a number of technologies, including aeroelastic tailoring to control structural divergence, use of a relatively large, close-coupled canard for longitudinal control, and control effectiveness at high angle of attack.

Seawolf Submarine

With its July 1997 commissioning, the U.S. Navy's Seawolf became the first new top-to-bottom attack submarine design since the introduction of the Skipjack class in the early 1960s. Inherent stealth, coupled with state-of-the-art sensors and advanced combat systems, make it one of the world's most formidable weapons systems.

Seawolf-class attack submarines provide robust open-ocean, sea-control capabilities against current and future submarine threats, as well as significant multi-mission littoral warfare capabilities.

Developer and manufacturer General Dynamics Electric Boat Corporation commissioned NTF aerodynamic studies to evaluate the initial Seawolf hull design to ensure optimal underwater performance.

Delta II Heavy Launch Vehicle

For two decades, Delta rockets served as NASA's primary launch vehicles for boosting communications, weather, science and planetary exploration satellites into orbit. A newer, more powerful Delta II version emerged in 1989, and was used for 151 launches until its retirement in November 2011.

A model of one of the Delta II 7000 variants – the "heavy" version – was evaluated at the NTF in an attempt to understand why its main engine deflections in the transonic flow regime were higher than those predicted by analysis.

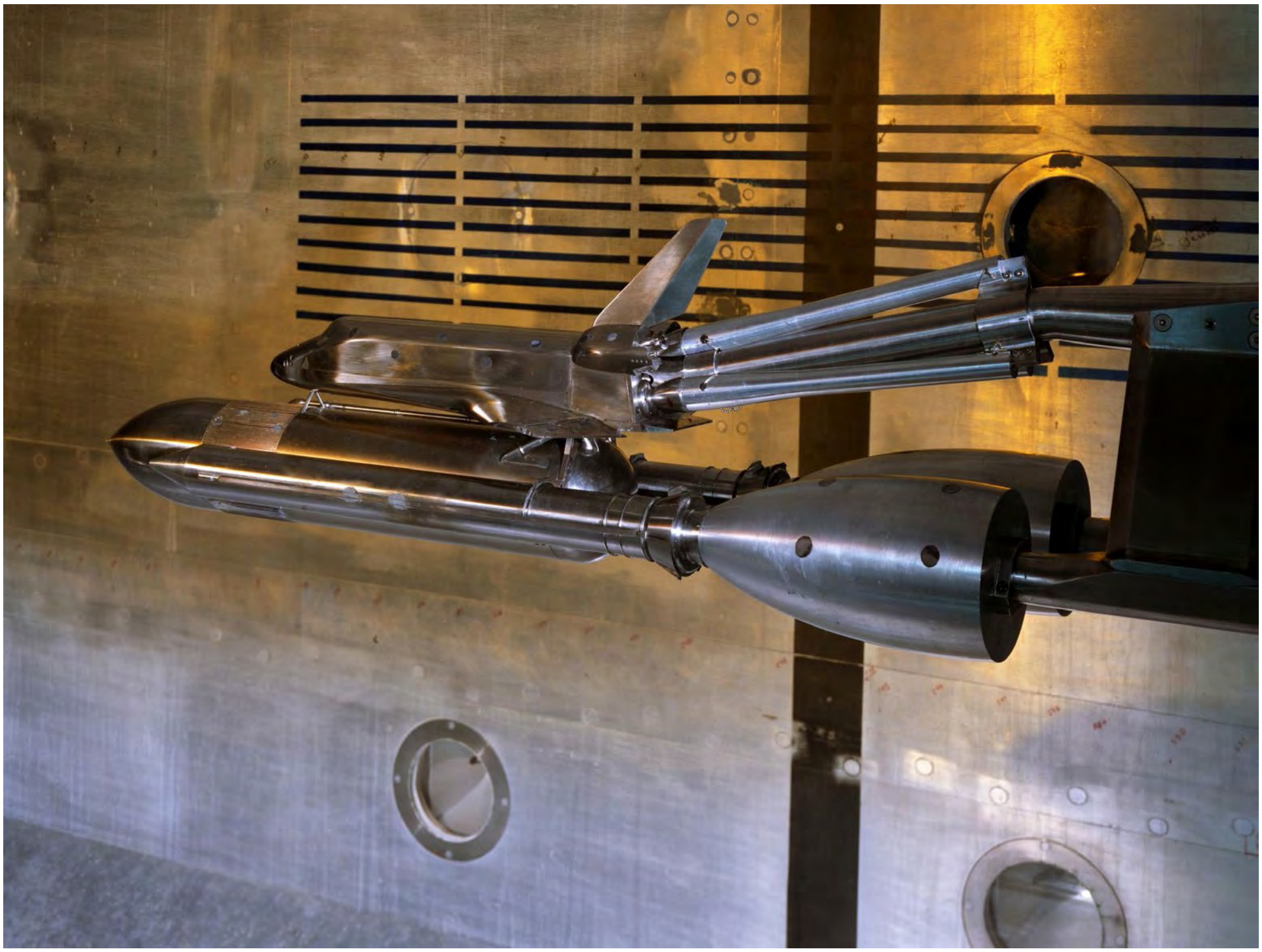
NASA worked closely with industry to improve engine-deflection predictions. NTF tests identified the multi-state nature of pitching moments over 60 seconds at constant tunnel conditions, detailed the flow physics, and improved the correlation between analysis and the conditions experienced during actual Delta II flight.

NOTABLE NTF STUDY DETAILS

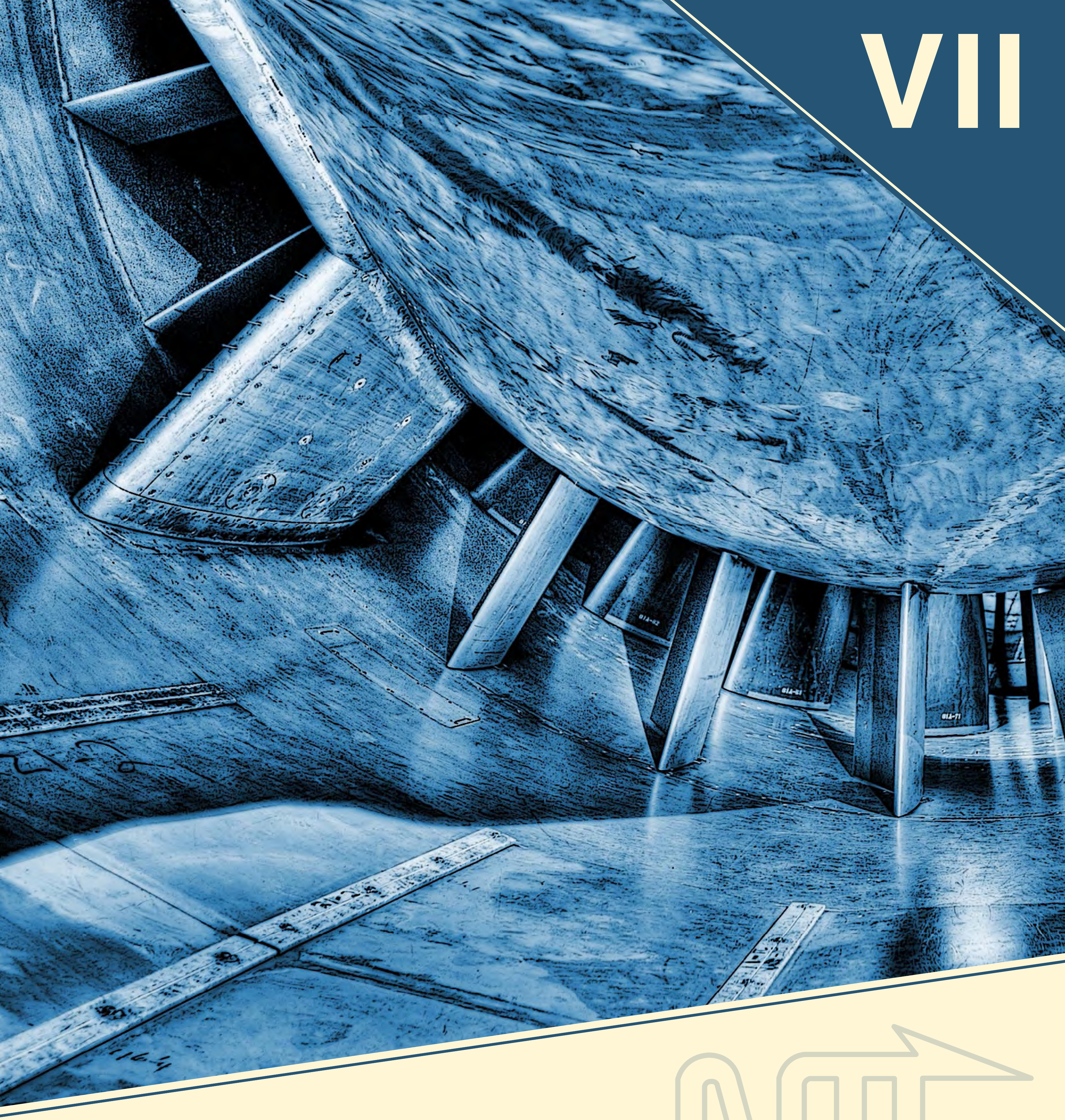
Space Shuttle, Shuttle Booster and Shuttle Booster Stack

A variety of initial designs and configurations of the space shuttle, including the shuttle booster and shuttle booster stack, logged almost 60,000 wind tunnel test hours in a dozen facilities across NASA Langley Research Center. Langley engineers contributed to the technology base for a reusable space vehicle, developing preliminary designs, and recommending the eventual shape be a modified delta wing, rather than a conventional straight wing.

In the NTF, a 0.01-scale model of the space shuttle ascent configuration was evaluated with an eye toward the rocket-gas plumes generated during launch.



VII



ORGANIZATION & MANAGEMENT

VII - ORGANIZATION and MANAGEMENT

The National Transonic Facility is part of a NASA Langley-wide concentration of subject-matter experts with internationally recognized core competencies in the aerosciences, acoustics, structures, and materials who identify and deliver solutions to complex aerospace systems challenges.

The NTF is operated by a contractor staff of dedicated and experienced staff of aerospace, mechanical, and electrical engineers, as well as mechanics, electricians, electronic technicians, programmers and systems operators dedicated to support testing and satisfying customer needs.

The organizational infrastructure is complemented by unmatched computational capabilities, including state-of-the art tools, access to world-renowned specialists, and extensive code validation. Test-article fabrication capabilities, advanced instrumentation, cutting-edge test techniques, a diverse, highly skilled and experienced workforce, and excellent data support are all available in a one-stop, ISO9001/AS9100-certified setting.

CONTACT

NTF CONTACT INFORMATION

NASA Langley Research Center
Facility Manager, National Transonic Facility
Mail Stop 267
Building 1236
5 West Taylor Street
Hampton, VA 23681-2199

Phone: 757-864-7576
Fax: 757-864-6557
Online: http://gftd.larc.nasa.gov

FACILITIES CONTACT INFORMATION

Chief Engineer for Test Operations Excellence
Mail Stop 225
NASA Langley Research Center
Hampton, VA 23681

Phone: 757-864-6885
Email: larc-dl-gftd@mail.nasa.gov
Online: http://gftd.larc.nasa.gov

VIII

FACILITY OPERATIONS

Work Schedule

The NTF can operate two 8-hour shifts, Monday through Friday. The first shift runs from 7:00 a.m. to 3:30 p.m. The second shift runs from 3:30 p.m. to 11:30 p.m.

In the event of severe weather (e.g. hurricane, ice storm, snowstorm) or a national emergency, call 757-864-2111 or 1-888-664-2111 to find out if the Center is open for normal operations.

General Safety and Security for Personnel

A safety briefing video is required viewing for all NTF customers at the start of every test to ensure your safety and understanding of the facility operations.

Other requirements are that:

- Badges must be displayed at all times while at Langley
- Visitors requiring escorts must stay with their escorts at all times
- You and your car may be searched entering or leaving Langley

Security Policy Requirements

NTF customers must provide their names to their Langley sponsor, who in turn will provide them to the Center's Security Services Branch (SSB). External customers' security offices must also provide the SSB with a visit authorization letter for each visitor.

For IT and non-escort access to the NTF, customers should contact the NTF facility manager at least two weeks prior to their visit and provide their full name, date/place of birth, social security account number, and citizenship status.

Once a NASA identity is established, IT security training and the NTF safety video will be available online through NASA's System for Administration, Training, and Education Resources (SATERN). Completion of this training prior expedites the process of badging and IT access.

Otherwise, upon customer arrival, Langley's Badge and Pass Office will issue a one-day paper badge, requiring NTF escort by authorized NASA Langley personnel. A full-duration badge will be issued following completion of the NTF safety briefing and written notification to the SSB by the facility safety lead/sponsor.

Requirements for access beyond Langley's normal operational hours of Monday through Friday from 6:00 a.m. to 6:00 p.m. must be requested in advance from the Center's chief of security who will coordinate approval with the Center director. Badges will be valid for the period identified on the request, not to exceed 179 days. If extensions are required beyond 179 days, the external customers must make application for NASA's personal identity verification protocol.

Prior to requesting unescorted NTF access for customers, sponsors must ensure the minimum requisite investigative information has been collected and verified. If so, the Badge and Pass Office will issue an unescorted badge to NTF customers. Otherwise, escort throughout the NTF is required at all times.

Upon completion of customer visits, the Langley sponsor is responsible for collecting any Center-access badges and returning them to the Badge and Pass Office.

Deviations of these procedures are not authorized. Any deviation could constitute a security violation and may cause removal of the external customer(s) from Center property.

Additional Requirements for NTF Access

- The NTF is a special-access building requiring RFID badges for entry
- Control Room access incorporates a second level of security. Your badge plus a PIN is required for entry
- Push-button cipher locks are used to limit access to specific rooms. Your assigned test engineer will provide the combinations as necessary

Tunnel Security and Access

- Pictures are typically allowed of the tunnel, tunnel systems and building. Please check with the facility manager, operations manager, or test engineer for any restrictions on photography or video capture of the facility and its systems
- Because the tunnel circuit is classified as a "confined space," do not enter the tunnel circuit without a facility staff member as an escort
- A lock out – tag out (LOTO) System is in place for securing systems. Do not touch any secured systems identified with LOTO red tags
- Wireless access is available for customer use (Details will be provided when onsite)

Meetings and Communications

Conference Rooms - Two conference rooms are available in the NTF. Please contact your test engineer for access.

Telephone - Several telephones are provided in the customer area and throughout the control room. The local area code is 757. (Note: The tunnel's steel structure may limit cellular phone signals for customers attempting calls from the NTF control room). To ensure prompt communication and information exchange, please share cell phone numbers with your test engineer.

The NTF-wide pager number is 712. On any facility phone dial 712, listen for the dial tone, leave your message, and then hang up.

Internal calls made to Center-dedicated landlines are made using a five-digit extension beginning with the numeral 4 and concluding with the four numbers specific to a given individual and/or office.

Phone Locations -

Location	Location in Room	Extension
Control Room (Rm 220)	Test Engineer Station	4-5176
N/A	Test Director	4-5121
N/A	Data System Operator Station	4-5178
N/A	Customer Station	4-4845
Model Prep Area 1	N/A	4-5173
Model Prep Area 2	N/A	4-5174
Model Prep Area 3	N/A	4-5172

For off-Center calls: Locally, dial 9, then the 7-digit number. For long distance, dial 9 + 1 + area code + the 7-digit number. Toll free, dial 9 + 1 + 8xx + the 7-digit number.

FACILITY OPERATIONS

Copying, Scanning, Printing and Faxing - Three multi-function devices in the NTF can copy, scan, fax, and print. These are located in or near the following locations:

Location	Fax Number
Room 130	757-864-6557
Room 210	757-864-6561
Control Room	N/A

Please note that a fax received at either of the two numbers above generates an electronic copy of the fax that is forwarded to the NTF administrative assistant who will deliver it to the recipient. Paper shredders are also located in the control room and customer work areas.

Mailing Address -

NASA Langley Research Center
Facility Manager, National Transonic Facility
Mail Stop 267
Building 1236
5 West Taylor Street
Hampton, VA 23681-2199

Breaks, Snacks, Housekeeping

Break Room - A break room is located on the 1st floor in room 107. This room has coffee, microwave ovens, a stove/oven, a refrigerator/freezer and vending machines.

Smoking is not permitted inside any of the NTF buildings. Smoking is permitted outdoors but preferably not in front of the building.

Control Room Snacking - The NTF discourages food in the control room. However, there are designated areas where food may be placed. All drinks must be in spill-proof containers.

Each day this area will be cleaned and any remaining food or drinks will be thrown away.

Cafeteria - Langley Research Center has a full-service on-site cafeteria, with a souvenir gift shop inside.

To reach the cafeteria, exit the NTF front door, turn left and proceed along W. Taylor Street to building 1213. It will be on your right.

Breakfast is served from 6:15 a.m. to 8:30 a.m. Lunch is available from 10:45 a.m. to 1:30 p.m.

Televisions - Several televisions – located in the NTF control room and conference rooms 108 and 202 – provide access to NASA programming and other channels.

Housekeeping - The trash cans in customer areas will only be emptied if they are placed outside the door.

EMERGENCIES

General Emergency - In the event of a general emergency, call 911 from any building phone. If you are calling from your cell phone while on site, dial 757-864-2222.

Calling 911 from your cell phone will connect you to the City of Hampton emergency response system rather than the NASA Langley (on Center) emergency crews.

Imminent Peacetime Emergency - Langley Research Center sirens – an audible 3-to-5-minute steady alarm – will be used to alert personnel of imminent peacetime emergencies such as extreme weather events.

Personnel should access the nearest Langley television, and tune to Langley Channel 11 for information.

Fire - Audible alarms are used to notify personnel of a fire. Occupants should leave the building immediately and muster in either of two areas: the building directly across the street from the NTF lobby entrance or in the parking lot southeast of the NTF, toward the Center main-gate side of the building.

To insure all customers are accounted for, please contact your test engineer once you are safely out of the building.

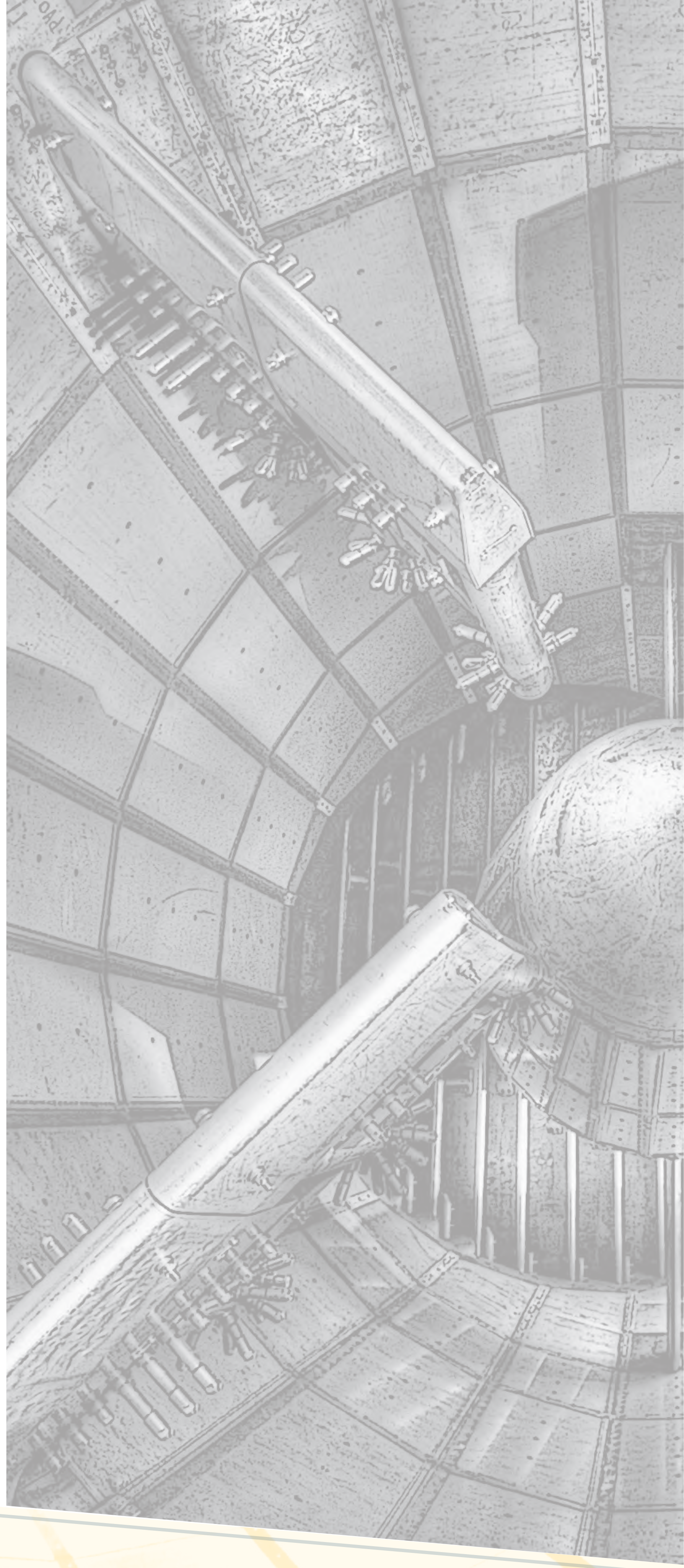
Low-Oxygen Warnings - Since the NTF utilizes gaseous and liquid nitrogen, low-oxygen conditions may arise in some areas of the building and create breathing hazards. Should oxygen content fall below 19.6%, blue warning lights will illuminate. Evacuate these areas.

Should oxygen content fall below 19.2%, audible alarms will sound. Follow the same procedures as described for fire emergencies.

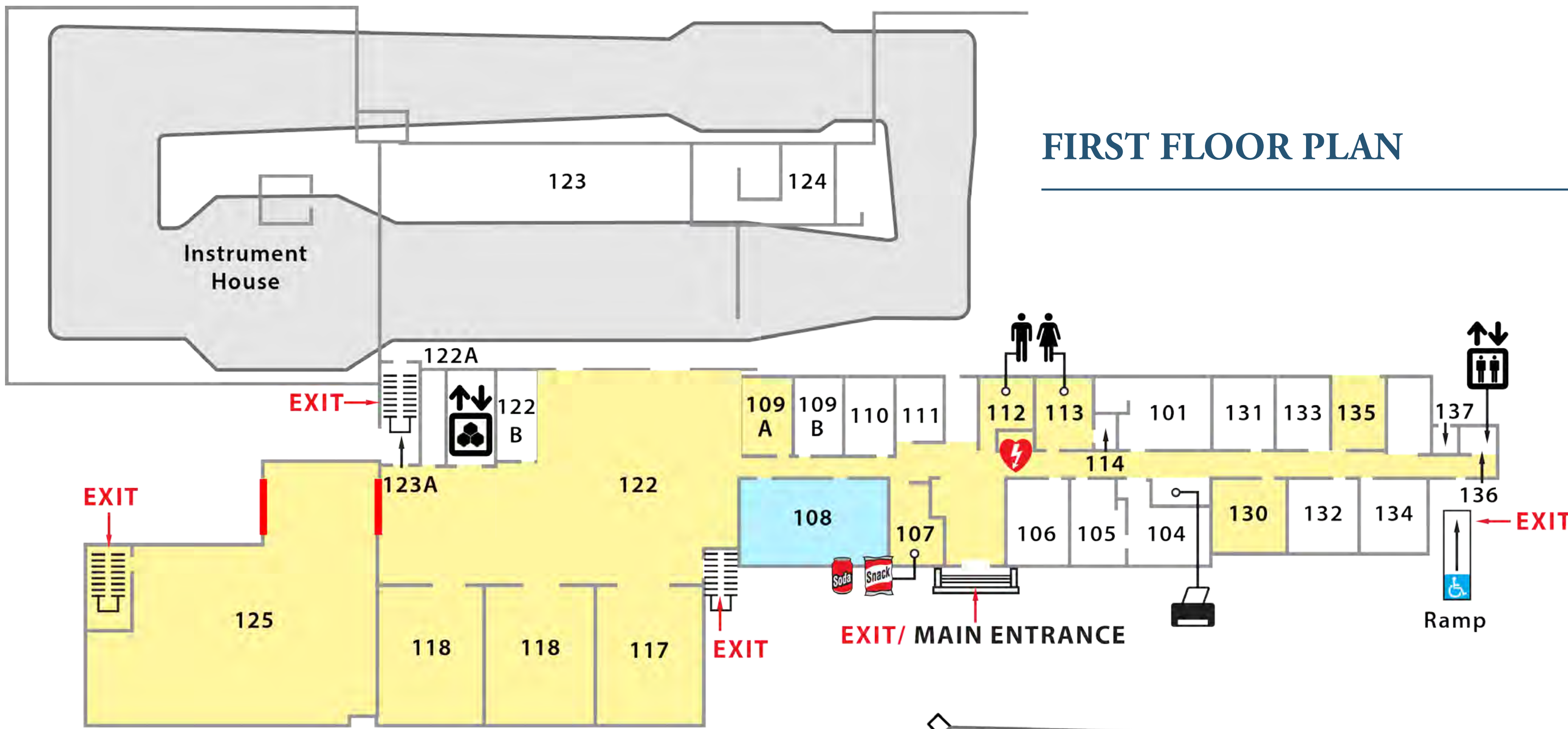
Foreign Object and Tool Control

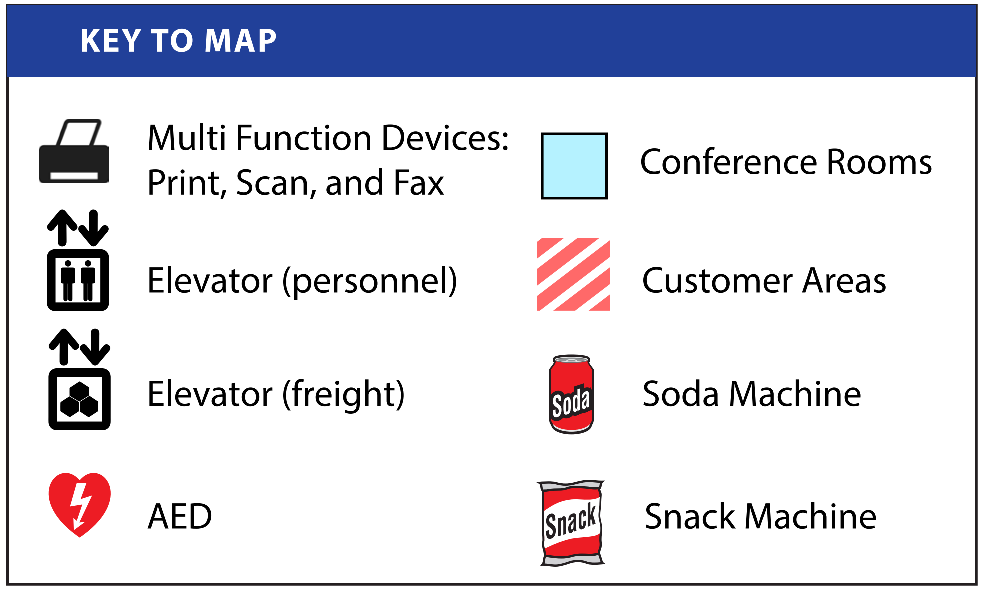
All personnel are responsible for keeping the tunnel circuit free of foreign objects and accounting for their tools. Lock boxes are located near the test section to secure personal items.

Please notify your Test Engineer if any item is missing. Please help keep the tunnel clean and undamaged.

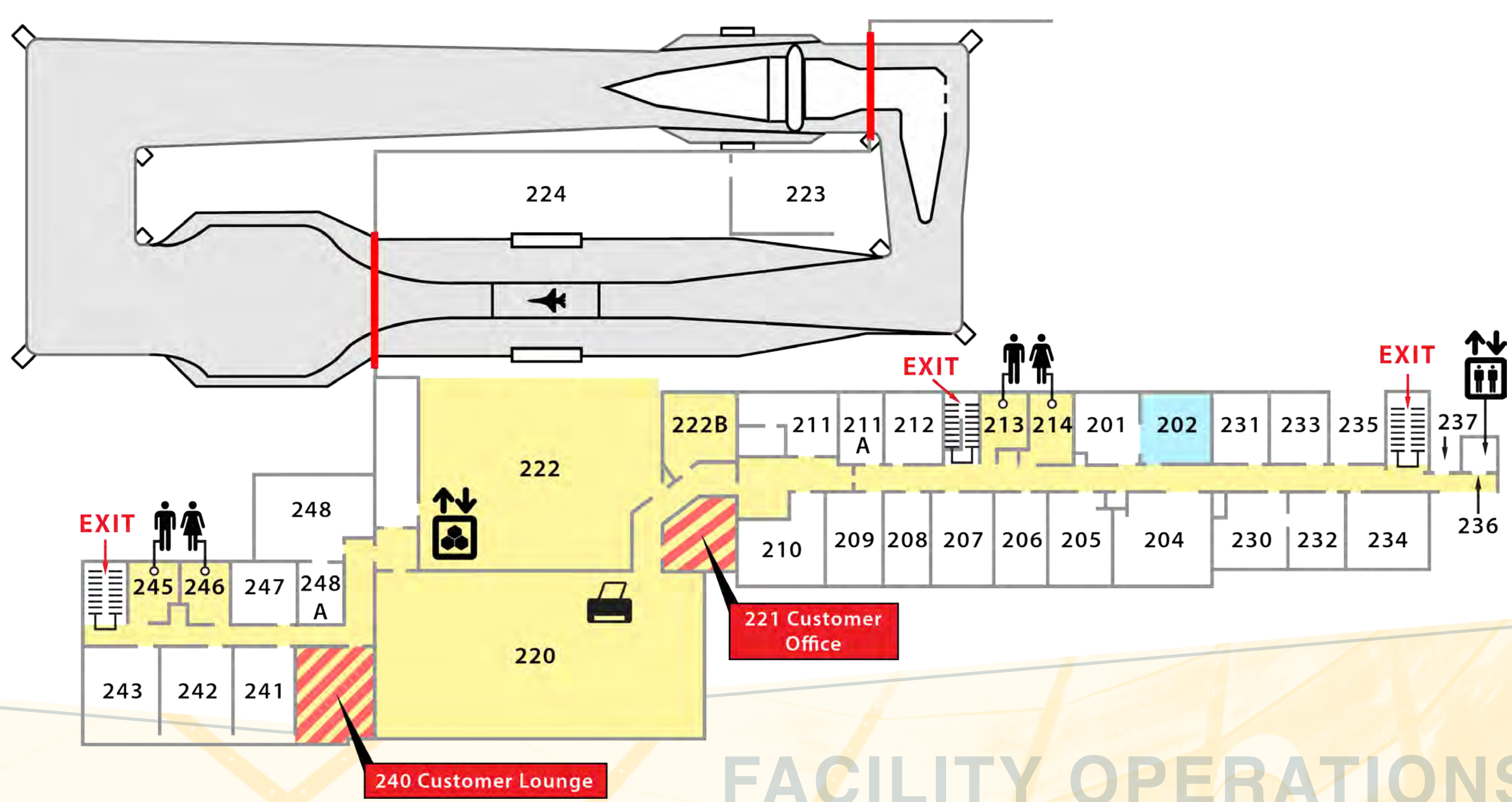


FIRST FLOOR PLAN





SECOND FLOOR PLAN



Areas Supported by NTF Operations

National Aeronautics and Space Administration
Langley Research Center
National Transonic Facility
Hampton, VA 23681

NP-2012-12-354-LaRC